GUIDELINES FOR THE PREPARATION OF COMMISSIONING AND TROUBLESHOOTING PROCEDURES: PACKAGED SOLAR DOMESTIC HOT WATER SYSTEMS

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Instrumentation A1

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1.0 INTRODUCTION

This manual is intended for manufacturers of package DHW systems.

This document presents general guidelines and procedures for solar systems in the areas of:

- Commissioning
- Operational Monitoring
- Troubleshooting

With this document as a guide, the manufacturer is expected to include, as part of the package, the instrumentation and test points required for the particular design. Manufacturers must also produce the appropriate documentation, including the commissioning, operational monitoring, and troubleshooting documents.

1.1 How To Use This Manual

This manual deals with the major areas of:

2.0 Commissioning
3.0 Operational Monitoring
4.0 Troubleshooting

Each of the above are dealt with in separate sections as indicated by the numbering. Each section outlines detailed requirements for the particular procedures to be followed and the documentation that must be produced.

Within each section is a basic "menu" for producing the appropriate documentation. In many cases, the manufacturer can simply use this as a draft of the documentation for the particular package and edit it to suit the design. Blanks indicated by a grey overtone are to be filled in by the design consultant, other blank will be filled out on site by the persons carrying out the procedures specified.

In many cases, instrumentation and test point requirements are duplicated. For this reason, specification of the instrumentation and test points required for those procedures are covered in Appendix A.

The following checklist will be helpful in carrying out the various steps required.

Step	Reference Section
1. Determine instrumentation requirements. Review instrumentation specifications and installation instructions. Select instrumentation.	Appendix A
2. Produce commissioning check list.	Section 2
3. Produce operations manual.	Section 3
4. Produce troubleshooting manual.	Section 4

1.2 Description of Procedures

Commissioning is a series of tests and inspections conducted by the system installers and witnessed by the Owner or his representative. The successful completion of these tests, as well as any required corrective action, should ensure that the installed package meets the design specifications.

Methods and procedures for the required commissioning tests are described in Section 2.0.

Operational Monitoring is performed by the system operator. Its function is to detect operating problems or a decrease in the performance of the system. The methods for this include:

- monthly inspections of the system and instrument readings,
- semi-annual detailed inspections and preventative maintenance.

Section 3.0 on Operational Monitoring provides a framework for the development of an operator's handbook for any specific liquid loop solar system design.

Troubleshooting, dealt with in Section 4.0, involves the diagnosis and correction of system operational problems or malfunctions. System problems should be initially identified by the system operator through the operational monitoring schedule. In the section on troubleshooting, a chart for use in identifying the likely cause of typical operating problems is presented. Also included are in depth discussions on some typical problems and solutions for solar systems components as an augmentation to the detailed troubleshooting chart.

1.3 Example Systems

To assist system designers in using this manual, a number of examples are presented. These examples include both a closed loop and a drain back system used for domestic hot water. **These examples are for illustrative purposes only and are not recommended designs.**

The two completely hypothetical systems used to illustrate the use of this manual are referred to as Systems A and B. Descriptions of these systems and the completed instrumentation selection and documentation of procedures are available as a separate volume entitled "Examples of the Preparation of Commissioning, Monitoring and Troubleshooting Procedures for DHW Systems For Pre-Engineered Liquid Loop Solar Heating Systems."

System A

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL CL5-6 - CLOSED LOOP

This system is a basic domestic hot water package system with a closed loop glycol collection loop.

This system is to be used with a conventional Domestic Hot Water tank.

System B

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL DB10-4 - DRAIN BACK

This system is a simple domestic hot water or process hot water heating system with a drain back water collection loop.

This system is to be used with a conventional Domestic Hot Water tank.

2.0 COMMISSIONING

Based on the procedures outlined in this section, the manufacturer of a solar heating package is expected to produce a commissioning document tailored to the specific model. The final commissioning document will, therefore, include those sections of the following menu which apply to the design of the package system.

2.1 MENU FOR PRODUCING A COMMISSIONING DOCUMENT

1. General Introduction to the Commissioning Document

2. System Inspection

3. System Tests

    System Pressure Test
    Verification of System Working Fluid
    Verification of Flow Rates and Directions
    Collector Array Balancing Check
    Verification of System Drain Back
    Control System Operation
    Heat Exchanger Operation

2.1. General Introduction to the Commissioning Document

The commissioning procedure is divided into two major sections. The first section details the inspections necessary to insure that the system is ready for commissioning. This includes checking for the instruments and test points required to carry out the commissioning procedures.

The second section is divided into a number of discrete tests. The performance and successful completion of these tests should insure that the installed system in general meets the manufacturer's design specifications. The specific design of any individual type of system will determine which of the tests outlined are applicable. In addition to the installed instrumentation and test points, the commissioning contractor will require the following system information and instrumentation:

System layout drawings and installation instructions

Pump performance curves

Antifreeze density chart and freezing point chart

An accurate electronic thermometer suitable for measuring pipe surface temperatures

A device for measuring antifreeze density

A device for measuring antifreeze pH

2.2. System Inspection

Carry out a general inspection of the system to insure that the system is complete and that all system components have been properly installed. This visual inspection should include:

A check of all plumbing connections to ensure that collectors, pumps, heat exchangers and other components have not been connected in a reverse direction.

A check to insure that all safety equipment such as temperature and pressure relief valves are present and have been installed in the correct manner. For systems requiring a non-toxic working fluid, check to insure that an appropriate label has been attached to the fill valve warning that only non-toxic fluid must be added.

A check to insure that all pipes are adequately sloped, at least 1 in 48, to insure that complete draining of the system is possible. This is particularly important for drain back systems.

A check of all pipe insulation to insure that the correct amount has been installed and that it is adequately secured and protected against water damage and ultraviolet deterioration.

A check to insure that all roof penetrations are adequately sealed.

A check of all wiring, both 110 volt and control wiring, to insure that it meets applicable electrical codes and that it is properly fastened to protect it against mechanical damage.

A check to insure that all instrumentation and test points required for carrying out the commissioning procedure have been

installed. This includes the control system run time meter, a flow indicating device and Peterson Plugs at the inlet and outlet of each pump.

2.3. System Tests

System Pressure Test

Pressurized systems should be pressure tested to the pressure specified by the manufacturer of the system. The specified pressure must be at least equal to the maximum pressure to which it may be subjected in service.

Specified pressure for primary loop pressure test [illegible] kPa

- completely fill the system with the proper working fluid.

- pressurize the system to the specified pressure and visually inspect for leaks.

- keep the system pressurized for a period of at least fifteen minutes. A pressure drop over this period, without a visual sign of leakage, could indicate an internal leak such as in a heat exchanger.

Fifteen minute test pressure used _____ kPa

Verification of System Working Fluid

For systems circulating other than potable water through the collector loop, it is important to insure that the proper antifreeze, in the proper concentration, has been used.

- obtain a sample of the working fluid and measure its specific gravity and acidity.

FLUID SPECIFIED BY SYSTEM MANUFACTURER	ACTUAL FLUID IN SYSTEM
Type of antifreeze	Type of antifreeze _____
Mixture specified	Actual Mixture
% antifreeze	_____ % antifreeze
% water	_____ % water
Specific gravity	Specific gravity _____
Freezing temperature °C	Freezing temperature _____ °C
pH	pH _____

Verification of Flow Rates and Directions

Initially, using the flow indicating device, ensure that flow has been established in the collector loop.

The flow directions and flow rates should be checked for all pumps associated with the solar heating system. For each pump:

- record the purpose for the pump (primary loop circulating pump, secondary loop circulating pump, repressurization pump, etc.)

Purpose for pump

- insure that all valves are in the positions required for normal operation of the system.

- with the pump operating, close the valve closest to the outlet of the pump and observe the pump outlet stagnation pressure.

Pump stagnation pressure _____ kPa

- slowly open the valve at the outlet of the pump and observe the pump outlet operating pressure. If this pressure is the same as the pressure recorded with the valve closed or the pressure drops as the valve is opened and then rises again to the previous pressure, an air lock or a restriction in the system should be suspected.

Pump outlet operating pressure _____ kPa

- measure the pump inlet pressure and compute the pressure rise across the pump.

Pump inlet pressure _____ kPa

Pump pressure rise _____ kPa

- using the characteristic curve for the pump, compute the flow rate.

Calculated flow rate _____ L/min

Flow rate specified by the manufacturer _____ L/min

If the system has an additional pump, repeat the procedure for that pump.

Purpose for pump _____

Pump stagnation pressure _____ kPa

Pump outlet operating pressure _____ kPa

Pump inlet operating pressure _____ kPa

Pump pressure rise _____ kPa

Calculated flow rate _____ L/min

Flow rate specified by the manufacturer _____ L/min

Collector Array Balancing Check

With the system operating on a sunny day, the collector array should be checked for proper connection and balancing. Automatic air bleed valves should also be checked for proper operation and setting.

- with a surface temperature measuring device, check the inlet and outlet temperatures from the collector array. If the temperature at the outlet of the array is not greater than the temperature at the inlet of the array, improper connection of the array may be suspected.

Collector array inlet temperature _____ °C

Collector array outlet temperature _____ °C

- check all automatic air bleed valves to insure that:
  - no air is present,
  - that associated isolation valves are open,
  - that protective caps are loosened to allow air to escape.

The remainder of this test need only be performed on systems which have collectors connected in parallel and use external headers.

- measure the temperature at the outlet of each individual collector. The outlet temperatures should all be within one degree Celsius.

Collector outlet temperatures _____ °C

_____ °C

_____ °C

_____ °C

_____ °C

Verification of System Drain Back

It is important to insure that drain back systems drain quickly and completely when required.

- for a system which drains automatically when the circulation pump stops, turn the controller to the off position when the system is filled and circulating and measure the time required for the system to drain completely.

- for systems which drain back at a predetermined collector temperature, turn off the controller for the drain back valve when the system is completely full and measure the time required for the system to drain completely.

If the actual liquid level in the drain back tank can not be seen, draining of the system will have to be detected by sound. Complete drain back should occur within three minutes.

Drain back time _____ min.

Control System Operation

The control system should be checked for proper operation. Due to the nature of the operation of a package solar heating system, the time required to observe the proper operation of the control system cannot be justified within this commissioning procedure. In lieu of actually observing its proper operation, it will be assessed on spot observations and on recordings of the control system run time meter.

- with the controls set for automatic operation, observe the solar storage temperature and determine, in light of the amount of solar radiation available, whether or not the system is performing properly.

- have the system installer record the date and time that the system is put into automatic operation and record the reading on the control system run time meter. If this data is not available, the reading taken during commissioning must be considered as the initial reading and a subsequent reading will be required at a later date. In either case, the two readings should be at least three days apart and a portion of the intervening time must have had weather suitable for the collection of solar energy.

  Readings taken by system installer (initial reading)

  Date _____ time _____

  Control system run time _____ hrs

- record the current reading (second reading)

  Date _____ time _____

  Control system run time _____ hrs

- calculate the total number of hours between the time the two readings were taken, and the total number of hours that the collector pump has operated during that time. The system should have operated between 10 and 60 percent of the total elapsed time, depending on weather conditions, time of year, load and other factors. If the system has not operated at all, or has operated continuously, a control system problem should be suspected.

  Total elapsed time _____ hrs

  Control system run time _____ hrs

  Control system operating factor _____ %

Heat Exchanger Operation

The heat exchanger should be checked to ensure that it is properly connected.

- record the inlet and outlet temperatures on both sides of the heat exchanger. For heat exchangers separate from the storage tank, ensure that the device is connected in a counterflow arrangement, that is, the hot connections of the two loops are close together and the cold connections of the two loops are close together. For in tank or wrap around heat exchangers, the hot collector fluid should enter at the upper connection and exit at the the lower connection.

For all heat exchangers record:

Collector loop inlet temperature _____ °C

Collector loop outlet temperature _____ °C

For separate heat exchangers record:

Load side inlet temperature _____ °C

Load side outlet temperature _____ °C

For in tank and wrap around heat exchangers record:

Solar tank storage temperature _____ °C

3.0 OPERATIONAL MONITORING

This section provides a framework and methodology for the development of an operator's manual for any specific solar system design.

Before the system operator can be expected to successfully perform the operational monitoring of a solar heating system, he must be made familiar with the general concepts and specific operation of his system. These tasks are accomplished in introductory sections to the operator's manual.

The approach taken in the development of operational monitoring procedures is to define key information for each system to ensure that:

- the system is working,
- durability is not degraded,
- efficiency remains near design and commissioning values.

While a specific solar system does not have a standard performance range, components of the system have performance ranges that are defined by the design specifications. The design specifications are verified by tests during the commissioning procedure and the resulting verified values become the standard performance values of the various components.

The next step is to define the monthly and semi-annual operational maintenance schedules.

A requirement of this section is to educate the operator to check important system characteristics against their acceptable range.

For each instrument reading, the operator must be supplied with the performance range or variation tolerance which is derived from the original design specifications and verified in the commissioning procedures. This will give him the necessary background knowledge to detect operational problems.

Monthly Inspections

Items that should be checked on a monthly basis are those that would indicate a system malfunction of an immediate nature. These are typically:

- system pressures,
- pump operation in relation to weather and control modes,
- status of system alarms,
- evidence of leaks or pressure relief valve activation.

Semi-Annual Checks

Semi-annual checks performed in the spring and fall will primarily involve closer examination of monthly checks following a slightly more detailed procedure.

Some typical semi-annual checks and tests include:

- fluid quality checks,
- checking on the condition of filters and strainers,
- testing of valves to insure functioning.

3.1 MENU FOR PRODUCING AN OPERATOR'S MANUAL

1. General System Description

2. System Operation

3. Introduction to Operational Monitoring

4. Operational Monitoring Procedures
   - Monthly Operational Checklist
     - Pumps
     - System Pressures
     - Fluid Level (Drain Back Systems only)
     - General Overview
   - Semi-Annual Operational Schedule
     - Run Time
     - Fluid Quality - Closed Loop Glycol System
     - Fluid Quality - Drain Back Systems
     - Drain Time - Drain Back System
     - Preventative Maintenance

Note: Italics are used to indicate direct instructions to the system manufacturer.

3.1. General System Description

This section should include an explanation of the possible uses for the solar system and the benefits it is likely to yield.

The general description of the solar system should include the basic system layout with a complete schematic diagram, as well as its basic principles of operation suitable for a person unfamiliar with solar technology.

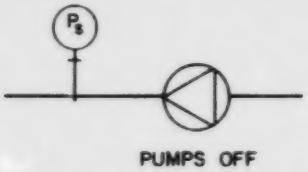
3.2. System Operation

Included here should be explanations of the various modes of operation of the system, with a detailed description of the system operation in each mode. These descriptions should go into enough depth that the function of all operating components of the system will be clearly understood. Particular emphasis should be placed on the operation of the control system. Include a system diagram indicating the location of all operational monitoring equipment and test points.

For each instrument, include a description of what it is measuring and an outline of the procedure to get the desired measurement. This will give the operator the necessary background to perform the monitoring tests. The following description can be edited to apply to any particular solar package.

In order to follow the operational monitoring schedule, the following measurements must be understood:

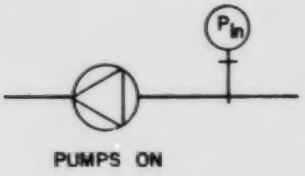
- system static pressure:



The static pressure is the pressure of the liquid in the piping system with the pumps off. The static pressure will be measured in both the primary loop (glycol) and

the secondary loop (water). The procedure is the same for both cases. With the pumps off, the pressure gauge just downstream of the pump measures the static pressure.

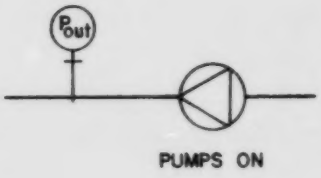
- inlet pump pressure:



The inlet pressure is the pressure of the liquid in the piping system just upstream of the pump when it is operating.

The inlet pressure will be measured in both the primary glycol loop and the secondary water loop. The procedure is the same for both cases. With the pumps on, measure the inlet pressure on the gauge just upstream from the pump.

- outlet pump pressure:



The outlet pressure is the pressure of the liquid in the piping system just downstream of the pump when it is operating.

The outlet pressure will be measured in both the primary glycol loop and the secondary water loop. The procedure is the same for both cases. With the pumps on, the pressure gauge downstream from the pump measures the outlet pressure.

- run time:

The run time meter attached to each controller clocks the time the

system is operating. This information is used to ensure that the system is operating approximately the expected amount of time.

- system alarm: The high limit thermostat sets off an alarm if the temperature of the fluid leaving the collector is too high.

3.3. Introduction to Operational Monitoring

The prime purpose of operational monitoring is to detect problems with the operation of the system. This is done by regularly comparing certain indicators, such as pressures and system run times with those specified in the design and commissioning process. A change in these indicators outside of the design range means that the system has an operational problem. Identifying operational problems or system breakdowns as soon as possible is important to reduce damage to the system, and will also maximize the energy output of the solar system. Early detection of problems will also increase the life of the system, and keep operating and maintenance costs to a minimum.

Checks of instrument readings and verifications of the operation or condition of component equipment are conducted on a monthly and semi-annual or yearly basis.

3.4. Operational Monitoring Procedures

Monthly Operational Checklist

To ensure that no major malfunction of the solar system has occurred, the following questions should be considered monthly. If the answer to any of

the questions is "no", a problem has been detected. To determine the cause of the problem and the required action, see the Troubleshooting Guide.

(a) Pumps

1. If the weather is sunny, or partially sunny, are the pumps operating?
2. If there is no sun, are the pumps off?

(b) System Pressures

3. Is the system static pressure within the acceptable range? (acceptable range: [illegible] kPa to [illegible] kPa)
4. If the pumps are operating, is the change in pressure across each pump in the specified range? (low, high) (acceptable range: [illegible] kPa to [illegible] kPa)
5. If the pumps are operating, is the discharge pressure relatively constant for each pump? (maximum deviation = [illegible] kPa)

(c) Fluid Level (Drain Back Systems Only)

6. If the system is not operating, is the fluid level in the drain down tank within the acceptable range? (acceptable level range within [illegible] cm of marked line)

(d) General Overview

7. Does the status of all system alarms indicate normal system operation?
8. Have pressure relief valves vented fluid?
9. Are the vibration and noise levels normal?
10. Is the temperature of all mechanical equipment normal? (no overheating)

Semi-Annual Operational Schedule

Twice a year, in the spring and fall, a more detailed version of the "monthly checks" should be performed. This procedure will provide a closer examination of the system to check for possible problems. The checks should be done on a day when solar energy is available and the system is cycling. Use the following procedure:

(a) Run Time

For each control module, read and record the run time. Subtract the previous month's reading to find the monthly run time. Compare this with the expected value for the month. Being high or low may be a result of abnormal weather, but may also be an indication of problems.

Expected Run Time	
	January
	February
	March
	April
	May
	June
	July
	August
	September
	October
	November
	December

(b) Fluid Quality - 1. Closed Loop Glycol System

1. Measure the specific gravity of the glycol-water mixture using a hydrometer. The specific gravity of the mixture indicates the percentage of glycol and water which

determines the freeze point of the solution. The specific gravity of the mixture must be greater than [illegible] and less than [illegible]. If it is out of the acceptable range, alter it by adding more water or glycol (type [illegible]).

2. Determine the pH factor (a measure of the acidity of the solution) of the mixture. In order to minimize corrosion, the pH of the solution must be greater than [illegible] and less than [illegible].

Fluid Quality - 2. Drain Back Systems

To control the entry of corrosion causing oxygen into the water of the collector loop, some drain back systems use an oil film on the top of the water in the drain back tank. If this is used, check the oil film thickness and replenish, if necessary.

If alternate corrosion inhibitors are utilized, include here the recommended procedure for checking them.

(c) Drain Time - Drain Back System

Manually stop the pump and measure the time taken for the fluid to completely drain. It should drain in less than [illegible] minutes.

(d) Preventative Maintenance

- clean collector glazing where necessary,
- inspect collectors for the following:
    - weep holes filled with debris, insects, ice, etc.,
    - deterioration of the absorber plate in the form of discolouration or buckling,
    - permanent condensation on the underside of the collector glazing,

- temperature variance: a collector that is noticeably cooler or warmer than the others indicates a flow blockage or imbalance,
- check mounting hardware security and caulking as well as flashing around roof penetrations,
- lubricate pumps, motors and control linkages as required,
- clean filters and strainers,
- cycle or operate valves to assure functioning.

4.0 TROUBLESHOOTING

Troubleshooting involves the diagnosis and correction of system operational problems or malfunctions. The procedures outlined in this section are designed to:

- assist the operator of the system in solving simple problems detected by the operational monitoring procedures,

- assist a technician in troubleshooting more extensive or difficult problems.

System problems should be initially identified by the system operator through his operational monitoring schedule. The Troubleshooting Guide should be based on observations stemming directly from these procedures.

When a system problem has been identified and is not corrected by the most obvious solutions, a troubleshooting engineer or technician must take a closer look at the problem.

The chart should be accompanied by an outline of procedures for problem isolation and correction which can assume the use of portable instrumentation using the monitoring point provisions included in the solar heating system design. The procedures can also assume that the person carrying out the test has a reasonable background in the troubleshooting of solar heating systems.

The suggested format is a chart organized on a component basis with separate sections for complex problems such as solving control system problems and a general deterioration of performance.

Sections 4.1 contains the general troubleshooting guide. The manufacturer of a solar system package may use this guide as a basis for his troubleshooting manuals by deleting those procedures not relevant to the particular package and modifying the others to suit the particular design. Troubleshooting of control system problems are detailed in Section 4.2, while Section 4.3 deals with diagnostic procedures for cases where the fault can not be traced to a single component.

4.1 TROUBLESHOOTING GUIDE

Symptom	Source	Cause	Action
No hot water	Make-up water shut-off valve	Valve closed	Open valve.
	Auxiliary heater	Failed to activate	Check breaker or fuse. Check power to heater. Check fuel supply.
Hot water temperature too low	Hot water thermostat	Thermostat setting too low	Set thermostat higher.
	Auxiliary heater	Not functioning	Check breaker or fuse. Check and repair auxiliary heating unit and fuel supply.
	Temperature modulating valve	Faulty	Repair or replace.
		Temperature set too low	Reset.
Water temperature too high	Hot water thermostat	Thermostat setting too high	Reset.
		Thermostat out of calibration	Recalibrate.
	Temperature modulating valve	Faulty	Repair or replace.
		Temperature set too high	Reset.
Insufficient hot water to load, but solar system seems normal	Auxiliary heater	Auxiliary heater problems	Check auxiliary heater, wiring, gas, oil lines, burners, and set points.
	Valves	Isolation valves improperly closed	Set in proper positions.
	Temperature modulating valve	Improperly adjusted	Check adjustment and adjust as necessary.
		Faulty	Repair or replace.

Symptom	Source	Cause	Action
Drop in water pressure at both hot and cold outlets	Inlet water pressure	Inlet strainer clogged	Clean basket.
	Pressure reducing valve	Malfunctioning	Check for plugged ports, and proper operation. Clean, repair, or replace.
Drop in water pressure at hot outlets only	Valves	Valve improperly closed	Open manual valves. Check automatic valve operation. Repair or replace.
		Jammed check valve	Repair or replace.
	Strainers	Flow restriction	Check and clean.
System does not start or Pump(s) not running when solar energy available	Power supply	Control switch in "off" position	Turn to "auto" position.
		No power to pump	Check fuses or circuit breaker.
			Check wiring and connections.
		No power to controller	Check fuses or circuit breaker.
			Check wiring and connections.
	Pump	Pump seized	Try turning by hand. Repair or replace.
		Motor failure	Repair or replace.
	Controls	Control failure	Try on "manual". If pump runs, suspect control system (Refer to Troubleshooting Controls).
		Pressure cut offs activated	Rectify cause, reset.
		Temperature cut off activated	If tank temperature is below the high limit cut off, check the control system (Refer to Troubleshooting Controls).

Symptom	Source	Cause	Action
		Fault in control system	Check control system (Refer to Troubleshooting Controls).
		Electrical problem	Check line terminal voltage.
Pump(s) running when no solar energy available	Control system	Control set on "manual"	Set on "automatic".
		Fault in control system	Check control system. (Refer to Troubleshooting Controls).
Pump cycling excessively	Controls	Incorrect set points	Check set point.
		Fault in control system	Check control system. (Refer to Troubleshooting Controls).
System static pressure low	Charge pressure low	Fluid level low	See "Fluid level low"
	Expansion tank (Diaphram)	Bladder capacity exceeded or diaphram leaking	Inspect for fluid in air chamber. Replace expansion tank.
	Expansion tank (Standard)	Inadequate air space	Adjust liquid level.
		Air leak	Find and correct.
Fluid level low	Leak in system	Piping leak	Repair. Replace wet insulation.
		Leak from drain	Close drain tightly, add cap.
		Leak from air vent	Inspect, clean mechanism. Repair or replace.
	Pressure relief valve	Relief valve has expelled excess pressure	Find cause for excess pressure; correct. Recharge system to operating pressure.
System static pressure high	Controls	Overtemperature	Find cause. (Refer to Troubleshooting Controls).
	Fluid	System overfilled	Check level.

Symptom	Source	Cause	Action
	Expansion tank	Expansion tank is waterlogged	Check expansion tank liquid level. Check for air leak.
Pump discharge pressure fluctuating	Pump	Cavitation	Find source of air entry, check for restriction on suction side, clean strainer.
System does not drain (Drain down systems)	Vacuum breaker	Damaged	Replace.
		Frozen	Thaw and protect from freezing.
	Piping	Piping not sloped adequately	Correct.
		Vent tube blocked	Check and clear.
	Controls	Control and sensor fault	(See "Troubleshooting Controls")
	Solenoid or motorized valve	Actuator defective	Replace.
		No power to actuator	Check wiring.
		Valve sticks	Repair or replace valve.
System will not fill with pump running (Drain down systems)	Pump	Cavitation	Check for air entry, check for restriction on pump suction side, clean strainer.
			Check for low fluid level in drain back tank.
System drains continuously with pump running (Drain down systems only)	Drain down valve will not close	Actuator defective	Replace.
		Power	Check wiring.
		Valve sticks	Repair or replace valve.
	Freeze protection thermal switch	Set point drift	Reset or replace.
		Defective	Replace.
		Loose contacts	Reconnect.
	Control sensors	Out of calibration	Recalibrate.
		Defective	Replace.

Symptom	Source	Cause	Action
Pressure does not drop when system filled (Syphon type drain back systems)	Piping	Leak in pipes causes break in syphon	Find and seal.
		Major flow restriction in system	Check position of all valves.
	Vacuum breaker	Faulty	Replace.
		Frozen	Thaw and protect from freezing.
	Fluid	Leak has reduced fluid level - no circulation achieved	Seal leak; refill system.
	Pump	Impeller fouled or damaged to point that pump cannot overcome static head	Clean or repair pump.
Storage temperature decays during periods of no load	Insulation	Damaged or wet	Repair or replace.
	Check valve	Reverse thermosyphoning	Inspect check valve operation. Repair or replace.
Storage temp. remains high during high load, little solar	Valves	Isolation valves improperly closed	Set in proper position.
Poor solar energy collection	Collector array	Film on collector glazing	Check for dirt on glazing. Check for condensation and outgassing. Clean glazing.
		New source of shading	Check for new structures, growth of trees, etc.
		Flow rate	Check flow rate. Reset to specified flow.
			Check operation of automatic flow control valve. Repair or replace as necessary.
		Flow balance	Check balance of flow through collector banks. Rebalance as necessary.

Symptom	Source	Cause	Action
		Flow balance	Check operation of automatic flow control valves. Repair or replace as necessary.
		Scale forming in collector tubes	Flush collector loop.
	Piping	Insufficient or damaged insulation	Check condition and adequacy of insulation. Repair, replace or add additional insulation.
	Collector fluid	Antifreeze/water concentration in collector loop fluid is improper	Check fluid properties. Follow manufacturer's recommendations.
		Reverse thermosyphoning	Inspect check valve operation. Repair or replace.
	Controls	Out of calibration	(See "Troubleshooting Controls.")
Excessive vibration or noise in system	Pump	Cavitation	Check for air entry, check for restriction on pump suction side. Clean strainer.
		Bearings	Check for hot or worn bearings. Check bearing alignment.
		Impeller	Inspect for misaligned shaft. Repair or replace.
			Check balance of impeller. Clean, repair or replace.
	Piping	Entrapped air	Check automatic air vents. Vent manually. Force purge system, find and correct source of air entry.
		Supports	Check condition and adequacy of hangers. Repair hangers or install additional hangers.
Water hammer	Automatic valves	Open or close too fast	Install valves with slower action. Modify controls to slow valve action.

The following section of the diagnostic chart will be helpful if the pump operating pressures as defined in the operator's manual, or the system ΔT (Temperature of fluid coming out of the collectors - Temperature of fluid going into collectors), are out of the specified range.

Symptom	Source	Cause	Action
Pump discharge pressure not in design range	If this condition is found carry out the following checks: 1. Check system static pressure and insure that it is in the proper range. 2. Using the pump inlet pressure and the pump discharge pressure, determine the pressure difference across the pump (ΔP).		
ΔP high		Generally the result of a flow restriction of some type	
	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with adjust flow as per commissioning procedure.
		Shut-off valves closed	Open.
		Automatic valves closed	Check controls, operation, and springs. Repair or replace.
	Check valve	Jammed	Repair or replace.
	Air vents	Faulty - causing air lock	Operate needle valve manually; check float control, inspect, clean, repair or replace.
	Collector	Passages clogged	Feel if some collectors hotter than others. Remove collector, backflush passages.
	Strainer	Flow restriction	Check and clean strainers.
ΔP Low	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with, adjust flow as per commissioning procedure.
	Three-way valves	Internal leaking	Check and repair.
	Pump	Cavitating	Find source of air entry. Check for flow restriction on suction side, clean strainer.
		Mechanical failure	Check and repair.

Symptom	Source	Cause	Action
ΔT low ΔP(s) normal	Collectors	Dirty	Clean surface.
		Insulation wet	Dry or replace insulation. Reseal collectors.
		Excessive condensation	Inspect seal, pipe gaskets, and weep holes. Repair.
	Pipe or tank insulation	Damaged, wet or missing	Repair or replace.
	Heat exchanger	Scaled up	Clean heat exchanger.
	Controls	Setting incorrect or drifting	Reset. (See "Troubleshooting Controls")
ΔT low ΔP(s) low	Flow control valves	Tampered with (opened)	Check seals on valves, if tampered with, adjust flow as per commissioning procedure.
	Three-way valves	Internal leaking	Repair.
	Controls	Incorrectly set	(See "Troubleshooting Controls")
ΔT high ΔP(s) normal	Controls	Incorrectly set	(See "Troubleshooting Controls")
ΔT high ΔP(s) low	Pump	Cavitation	Find source of air entry, correct, clean strainer, check for restriction on suction side.
		Impeller damage	Check stagnation pressure. Repair.
	Three-way valves	Internal leak	Check and repair.

Symptom	Source	Cause	Action
ΔT high ΔP high		Generally the result of a flow restriction of some type	
	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with, adjust flow as per commissioning procedure.
		Shut-off valves closed	Open.
		Automatic valves closed	Check controls, operation, and springs. Repair or replace.
	Check valve	Jammed	Repair or replace.
	Air vents	Faulty - causing air lock	Operate needle valve manually; check float control, inspect, clean. Repair or replace.
	Collector	Passages clogged	Feel if some collectors hotter than others. Remove collector, backflush passages.
	Strainer	Flow restriction	Check and clean strainers.
Pump run time too high			(See "Pump(s) running when no solar energy available")
Pump run time too low			Check ΔT and ΔP(s) and refer to appropriate section, if cause not evident, refer to "System Diagnostic Procedures".

4.2 TROUBLESHOOTING SOLAR CONTROLS

In troubleshooting solar controls, it is important to use a logical and systematic approach to isolate and correct system faults. The following is the recommended procedure. This procedure is for variable resistance type controllers. For I.C. controllers which use variable voltage sensors, voltages are measured instead of resistances.

Differential Controller Checks

1. Check power supply to controller.

2. Check that all components are wired correctly to controller (according to manufacturer's specifications).

3. If the pump or valve does not work in the "manual" mode, disconnect it from the controller and apply rated voltage to its input wires at the controller.

   a. If it runs, the pump is all right - the problem is in the control system.

   b. No operation - the pump or valve is faulty or the interconnecting wiring or relay is faulty. Isolate the fault and repair or replace the defective component.

4. Check all sensors for:

   - proper location,
   - secure attachment with no corrosion build up,
   - proper wiring to controller.

5. Check each sensor for proper resistance by disconnecting it at the controller. If the measured resistances are as specified, the fault is a controller problem. Proceed to Step 8. If the measured resistances do not correspond to the specification value for the temperature of the sensor location, then:

   - the sensor is faulty,
   - the interconnecting wiring is faulty.

6. Disconnect sensor from wiring leading to the controller. Check the sensors resistance at this point. If the resistance is not to specification, replace the sensor.

7. If sensor is accurate, check for corrosion at all wiring connections. Clean, reconnect and remeasure resistance at the controller. If the measured resistance is still not correct, replace the wiring between the sensor and the controller.

8. Controller operational check.

   - switch off the electrical power to all pumps and/or control valves and make sure the controller is set for the recommended temperature differential;

   - replace the temperature sensors at the collector and the tank with variable resistors (variable resistors with readouts will simplify the procedure). The resistors can be connected to the sensor terminals at the controller;

   - from the temperature sensor characteristic curve, determine the resistance associated with $5^{o}C$ absolute temperature;

   - dial this resistance into the variable resistor on the output to the tank sensor. Record the resistance;

- with the controller set in the automatic position, gradually change the resistance on the collector side until an output is measured at the controller output terminals (to pump or control valve). Record the indicated resistance;

- vary the resistance until there is no longer an output at the controller output terminals. Record the indicated resistance;

- reset the tank variable resistor for the resistance associated with a 15°C absolute temperature;

- repeat the above procedure determining the collector resistance to receive an output at the output terminal and the resistance to receive no output. Record both resistances;

- calculate the differential resistance, and from the temperature sensor characteristic curve determine the temperature differential;

- compare this with the original setting of differential temperature;

- if the two figures disagree substantially (more than 10 per cent), adjust the controller setting and repeat the above test.

9. Sensor Calibration Check

Preparation

1. Obtain a copy of the temperature sensor characteristic curve from the manufacturer (resistance vs. temperature).
2. Use a digital multimeter with an appropriate probe to determine as accurately as possible the temperature at the point the sensor is intended to sense.

Method

Determine the temperature at the point the sensor is intended to sense. These will likely be the temperature on the absorber plate in one of the collectors and the temperature in the lower third of the storage tank.

Measure with an ohm meter the resistance shown by the sensor. This should be done at two temperatures for each sensor, for example:

For collector sensors:

1. Cool Temperature - as early as possible in the morning, preferably on a cloudy day.
2. Hot Temperature - mid to late afternoon on a sunny day.

For storage tank sensors:

1. Cool Temperature - after a major draw of heat from storage to load on a cloudy day and before the auxiliary heat has replenished the draw (where applicable).
2. Hot Temperature - late on a sunny day before a major draw of heat or on a day when the load is reduced.

Compare the measured resistance with that shown on the manufacturer's table or graph for the appropriate temperature.

If the resistance varies from the expected value, the sensor or sensor lead connections may be corroded or the sensor may have been damaged by heat extremes. Check both and replace as necessary, then repeat the test.

Freeze Protection Controls

Thermal switch sensors are used for freeze protection of the collector loop on drain back systems or heat exchangers on closed loop systems.

The freeze protection set point should be at least $3^{o}C$ ($5^{o}F$) above the actual freezing point. Once the thermal switch set point is reached, the switch should de-activate the pump on drain back systems, causing the system to drain. In closed loop glycol systems, the freeze protection thermal switch circuit prevents the pump running due to controller failure.

Sensors used for freeze protection may be either the thermal switch type or variable resistance type.

Test Procedure for Thermal Switch Type

1. Connect the thermal switch to an ohm meter so you can see when it changes state. Seal the sensor along with a thermometer in a plastic bag. Place the bag into cool water and add ice for further cooling. When the sensor changes state, record the temperature and ohm meter reading. Slowly warm the water and sensor until it changes state again. Record the temperature and ohm meter reading. The first set of readings is the low temperature limit set point and the second is the temperature at which heat collection can restart.

2. After checking the thermal switch, connect it to the controller or pump circuit and retest by varying the temperature as described, and verify that the proper response occurs.

Test Procedure for Variable Resistance Types

1. If freeze protection circuit uses a thermistor, nickel wire or film as its sensor, then a variable resistor whose resistance range passes through that of the low temperature set point should be connected to the collector sensor inputs. A resistor with a value somewhat less than the collector freeze point should be connected to the storage input. With the appropriate load connected to the controller, connect the controller to the power input. The variable resistor should be varied above and below the freeze protection set point. Verify that the appropriate response occurs at the temperatures and resistance values specified by the manufacturer.

High Temperature Limit Protection

High temperature limit switches are used in solar systems either to protect collectors and storage tanks or as a secondary safeguard against failure of the mixing valve on the outlet to load.

The collectors are normally designed to withstand the stagnation temperatures and thermal shock associated with this. Control logic should be set up so that the temperature limit switch will not inhibit the initial start up of the collector loop pump, but will activate if, after a reasonable length of time, the collector temperature has not fallen.

For closed loop glycol systems, the high temperature limit or control logic may be used to divert flow to a heat purge coil.

High Temperature Protection for Storage Tanks

High temperature limit switches are used to protect storage tanks from over temperature conditions. In some cases, a tank temperature limit can serve as a secondary protection against scalding temperatures being delivered to the load if the mixing valve fails.

High Temperature Limit Switch Checkout

The checkout procedure is similar to that for freeze protection. The switch or sensor is immersed in hot water, which is heated until the device activates and then cooled until it reverses. The temperatures and resistances for these points are recorded and checked against the specification.

4.3 GENERAL SYSTEM DIAGNOSTIC PROCEDURE

The performance of a solar system depends on the interaction of all system components, outside conditions, and the load imposed on the system.

There are cases in which a general decrease in the performance of a system is indicated by a decrease in system operating time, temperature differences, measured energy collected, or by an increase in the required auxiliary energy. In some cases, the particular problem cannot be isolated by the operator. The following is a general diagnostic procedure which can, in most cases, isolate the causes.

Carrying out this procedure requires some knowledge of solar systems and a number of portable instruments; therefore, a troubleshooting technician or engineer may be required.

1. The first step is a visual inspection of the system paying special attention to such items as completeness and condition of insulation and whether the collectors are clean and free of new shading.

2. Verifying flow rates.

   The operating flow rates in each loop should be checked by the means provided. This may be by using pump differential pressures or by reading a flow meter if one is installed in the particular loop. (See commissioning procedure.)

3. If the flow rate in any loop in the system is lower than specified the flow, restriction can be isolated by checking the pressures at the monitoring points provided in the system and comparing these with the commissioned values.

4. If the flow rates in all points of all loops are as specified, check the fluid temperatures at each monitoring point on a clear sunny day.

5. Verify the flow balance through the collectors.

   The face temperature of each collector should be checked by feel or, preferably, with a pyrometer. Collectors that are significantly warmer or cooler than their neighbours indicate flow blockages and stagnation or high flows respectively.

   It is a good idea to check the bank temperature balance by the method shown in the commissioning procedure.

6. Verify the effectiveness of the heat exchanger as in the commissioning procedure. A reduced effectiveness could indicate scaling of the heat exchanger surfaces.

7. Perform the preliminary thermal performance test as shown in the commissioning procedure and compare the efficiency with the commissioned values. This will detect degradation of the collectors' performance.

8. Check the calibration of the control system as described in "Troubleshooting Solar Controls."

If satisfied that the operating characteristics of the system are normal, investigate the non-operating features.

9. Isolate the system from load and bring the storage temperatures up during the day. Read the storage temperature at nightfall and shut off the system. Check the storage temperature in the morning. If the storage temperature has dropped significantly, suspect damaged or wet insulation, or reverse thermosyphoning (usually the result of a faulty check valve).

APPENDIX A INSTRUMENTATION

A1 Required Instrumentation

The following instrumentation is required in DHW packaged systems:

- Peterson Plugs on the inlet and outlet of each pump. (Note: if pumps are in parallel, only two Peterson Plugs are required; one in the suction line and one in the discharge line. If two or more pumps are in series, two Peterson Plugs will be required for each pump),

- an elapsed-time meter to monitor each control system in the package,

- a flow-indicator on the collector loop,

- a pressure gauge to be used with a Model 500 Peterson Plug adapter.

A2 Instrumentation Specification

Peterson Plugs

Peterson Plugs, part Number 110 - 1/4 inch brass with nordel core, are manufactured by Peterson Equipment Co., P.O. Box 217, Richardson, Texas. These devices are installed in elbows in all cases. Figure A1 illustrates the installation. They are available through:

Ontario Mechancial Sales and Services Inc.
4325 Steeles Avenue West
Downsview, Ontario
M3N 1V7
(416) 663-5530

and

C. R. Wall and Co. Inc.
East Lambeth Plaza
Campbell Street & No. 2 Highway
P.O. Box 280
Lambeth, Ontario
N0L 1S0
(519) 652-2490

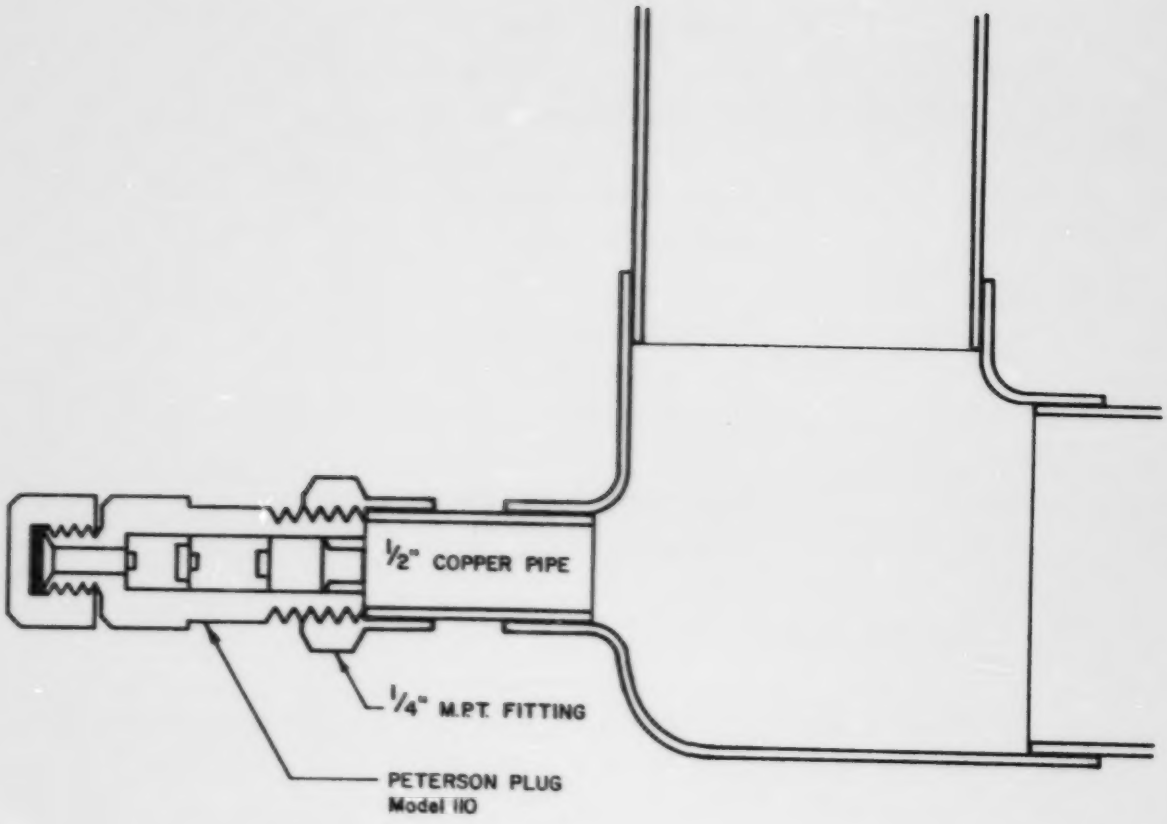


FIGURE A1
Peterson Plug Installation

Flow Indicator

Minimum specifications include:

- 700 kPa pressure rating,
- 100°C temperature rating.

Inexhaustive list of suppliers include:

RADA Mechanical Products Ltd.
Markham, Ontario

DRY-CON Inc.
840 Halpern Ave.
Dorval, Quebec

HIGGINSON Equipment Sales Ltd.
Burlington, Ontario

Pressure Gauges

Select a gauge equivalent to "Trerice" or "Winters" with a sufficient range for the solar system.

The pressure gauge will be temporarily inserted into Peterson Plugs when required.

Run Time Meter

Characteristics of the required run time meter include:

- electro-mechanical, 110 volt, AC synchronous motor-driven counter
- non-resettable, 6-digit hour and tenths of hour indicator
- CSA approved

Use a Bach Simpson Number 1357 ETIF or equivalent.

Install in accordance with the manufacturer's instructions.

EXAMPLES OF THE PREPARATION OF COMMISSIONING, MONITORING AND TROUBLESHOOTING PROCEDURES FOR DHW SYSTEMS

For Pre-Engineered Liquid Loop
Solar Heating Systems

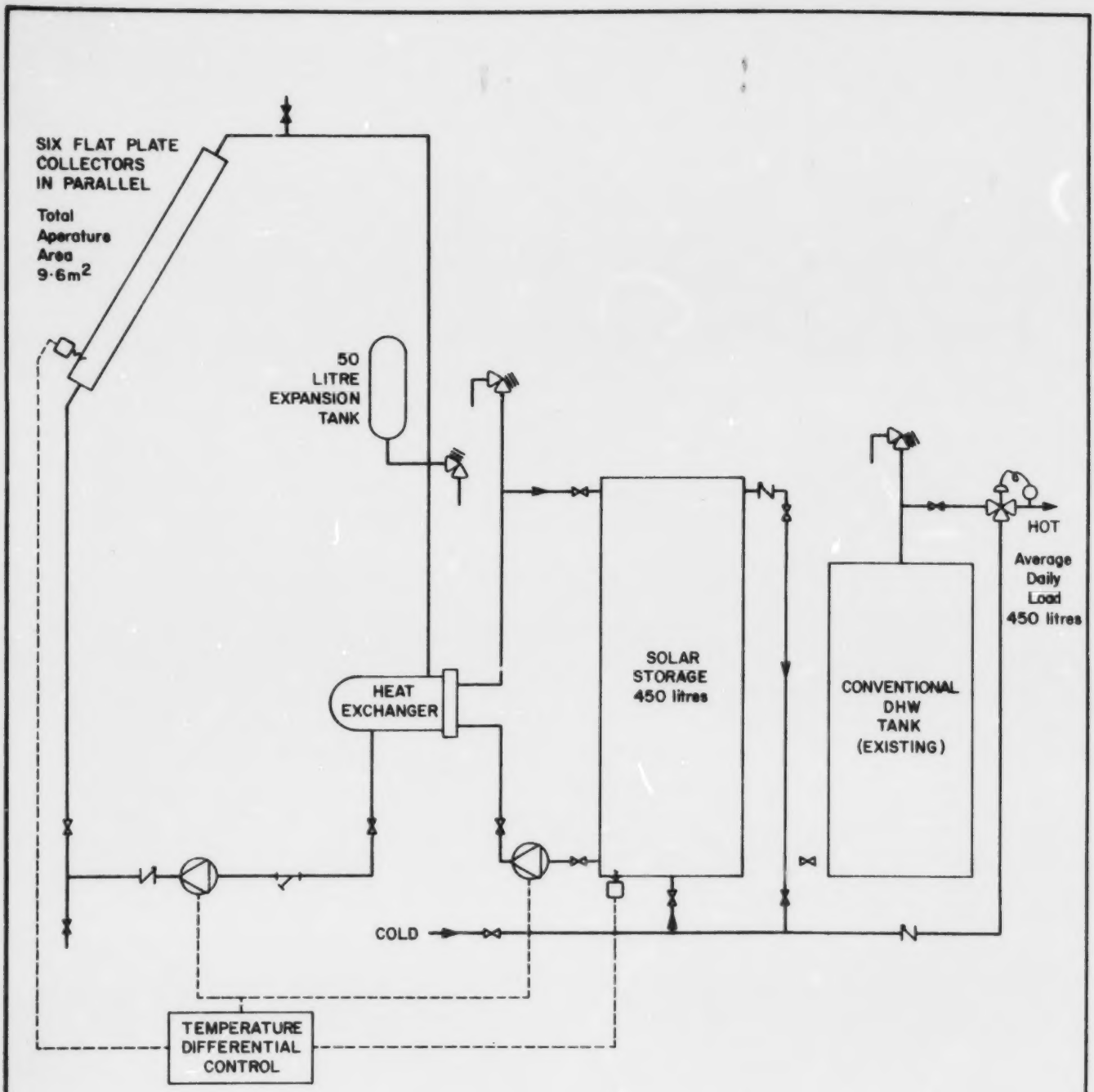
Solar Programs Office
Public Works Canada
Ottawa

EXAMPLE SYSTEM "A"

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL CL 5-6 - CLOSED LOOP

This system is a basic domestic hot water package system with a closed loop glycol collection loop.

This system is to be used with a conventional Domestic Hot Water tank.



DATE	MARCH, 1982		
DESIGNED	S.B.		
DRAWN	G.B.		
CHECKED	P.T.		

Illustration Solar Manufacturing

Domestic Hot Water Package

Schematic
Model CL 5-6 Closed Loop

SCALE	PROJECT NO.	DWG. NO.	REV.
N.T.S.	81-56	1	

SYSTEM "A"

SELECTED INSTRUMENTATION

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL CL 5-6 - CLOSED LOOP

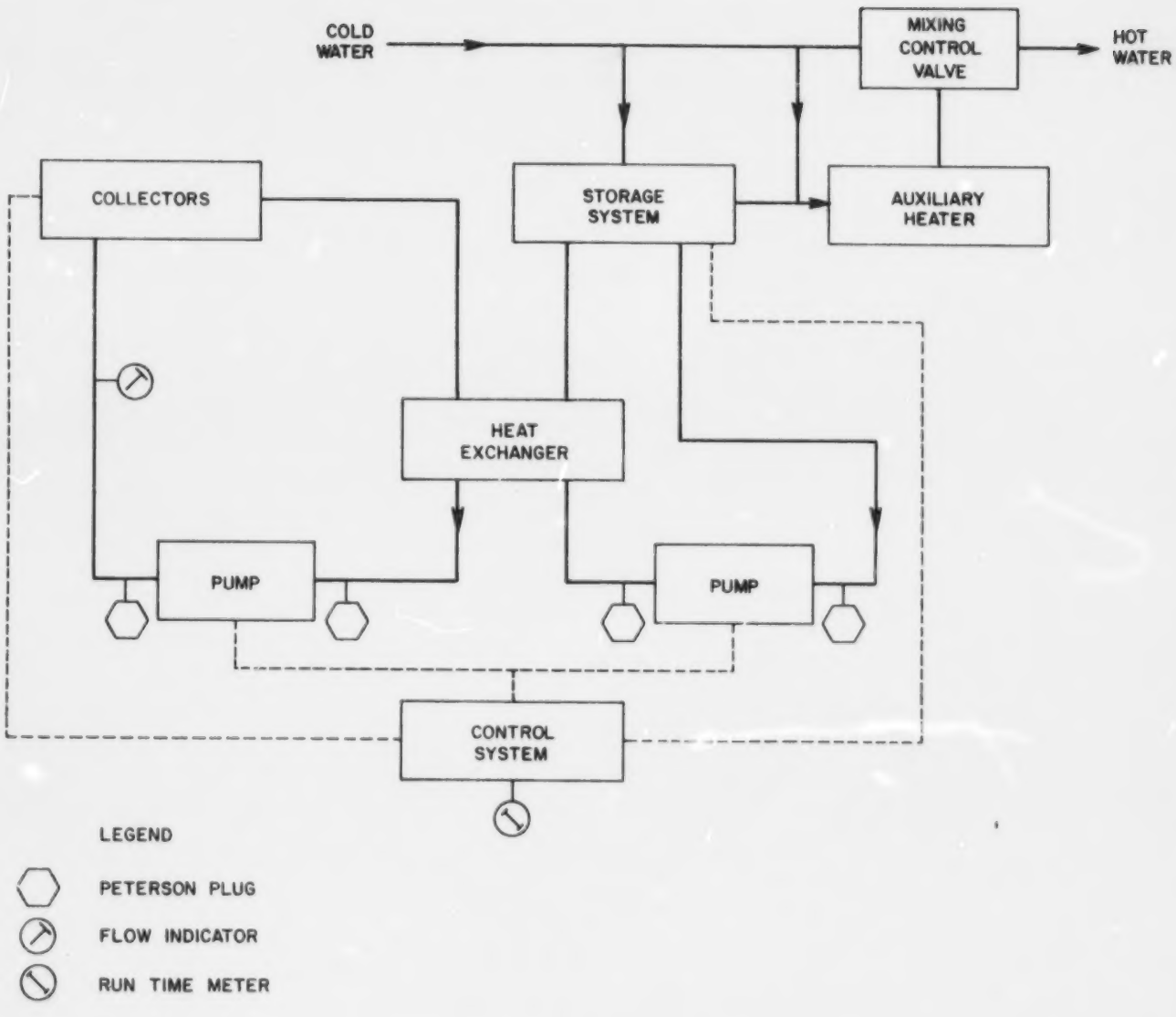
List of Required Instrumentation

1. Four Peterson Plugs, part number 110, to be installed in elbows at the specified locations on the inlet and outlet of each pump.

2. One Bach Simpson Number 1357 ETIF elapsed-time meter to be installed to monitor the control system.

3. One flow indicator to be installed in the collector loop.

4. One Winters pressure gauge with a range from 0 to 400 kPa to be used with a Model 500 Peterson Plug.



SYSTEM A
Illustration Solar Manufacturing
Domestic Hot Water Package
Model CL 5-6 Closed Loop

Modular Representation with Instrumentation

COMMISSIONING DOCUMENT

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL CL 5-6 - CLOSED LOOP

INDEX

1. General Introduction to the Commissioning Document

2. System Inspection

3. System Tests
   - System Pressure Test
   - Verification of System Working Fluid
   - Verification of Flow Rates and Directions
   - Collector Array Balancing Check
   - Control System Operation
   - Heat Exchanger Operation

1. General Introduction to the Commissioning Document

The commissioning procedure is divided into two major sections. The first section details the inspections necessary to insure that the system is ready for commissioning. This includes checking for the instruments and test points required to carry out the commissioning procedures.

The second section is divided into a number of discrete tests. The performance and successful completion of these tests should insure that the installed system in general meets the manufacturer's design specifications. In addition to the installed instrumentation and test points, the commissioning contractor will require the following system information and instrumentation:

System layout drawings and installation instructions

Pump performance curves

Antifreeze density chart and freezing point chart

An accurate electronic thermometer suitable for measuring pipe surface temperatures

A Winters pressure gauge with a range from 0 to 400 kPa

A device for measuring antifreeze density

A device for measuring antifreeze pH

2. System Inspection

Carry out a general inspection of the system to insure that the system is complete and that all system components have been properly installed. This visual inspection should include:

A check of all plumbing connections to ensure that collectors, pumps, heat exchangers and other components have not been connected in a reverse direction.

A check to insure that all safety equipment such as temperature and pressure relief valves are present and have been installed in the correct manner. For systems requiring a non-toxic working fluid, check to insure that an appropriate label has been attached to the fill valve warning that only non-toxic fluid must be added.

A check to insure that all pipes are adequately sloped, at least 1 in 48, to insure that complete draining of the system is possible.

A check of all pipe insulation to insure that the correct amount has been installed and that it is adequately secured and protected against water damage and ultraviolet deterioration.

A check to insure that all roof penetrations are adequately sealed.

A check of all wiring, both 110 volt and control wiring, to insure that it meets applicable electrical codes and that it is properly fastened to protect it against mechanical damage.

A check to insure that all instrumentation and test points required for carrying out the commissioning procedure have been installed. This includes the control system run time meter, a flow indicating device and Peterson Plugs at the inlet and outlet of each pump.

3. System Tests

System Pressure Test

Pressurized systems should be pressure tested to the pressure specified by the manufacturer of the system. The specified pressure must be at least equal to the maximum pressure to which it may be subjected in service.

Specified pressure for primary loop pressure test 185 kPa

- completely fill the system with the proper working fluid.

- pressurize the system to the specified pressure and visually inspect for leaks.

- keep the system pressurized for a period of at least fifteen minutes. A pressure drop over this period, without a visual sign of leakage, could indicate an internal leak such as in a heat exchanger.

Fifteen minute test pressure used _____ kPa

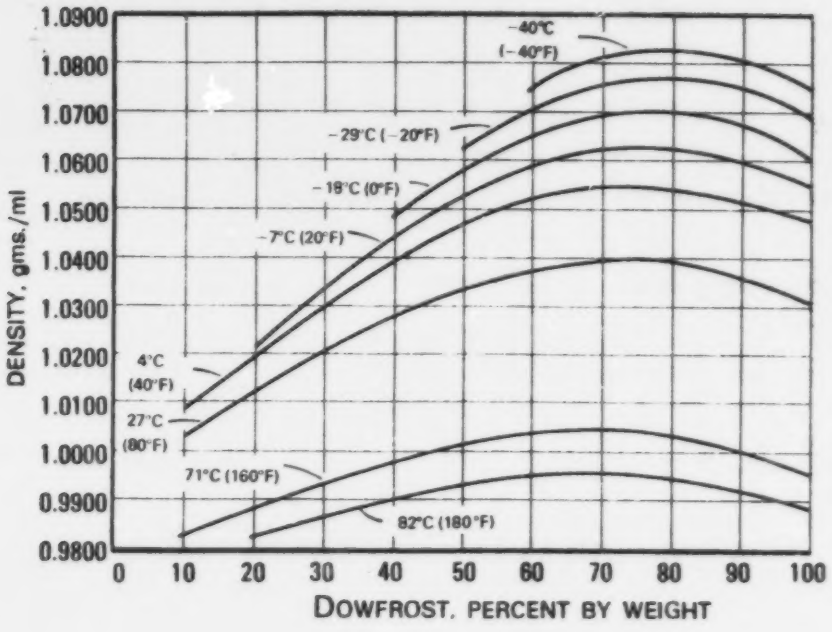
Verification of System Working Fluid

For systems circulating other than potable water through the collector loop, it is important to insure that the proper antifreeze, in the proper concentration, has been used.

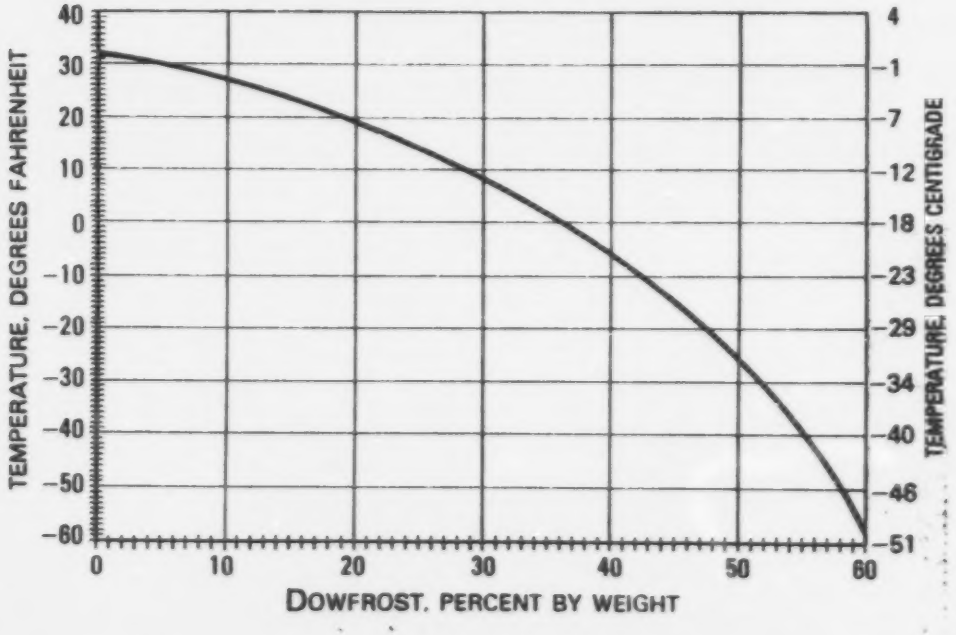
- obtain a sample of the working fluid and measure its specific gravity and acidity.

FLUID SPECIFIED BY SYSTEM MANUFACTURER	ACTUAL FLUID IN SYSTEM
Type of antifreeze propylene glycol	Type of antifreeze _____
Mixture specified	Actual Mixture
50 % antifreeze	_____ % antifreeze
50 % water	_____ % water
Specific gravity 1.034 kg/L at 25°C	Specific gravity _____
Freezing temperature -31 °C	Freezing temperature _____ °C
pH 9.8	pH _____

Density of Aqueous Solutions of Antifreeze



Freezing Point of Aqueous Solutions of Antifreeze


TEMPERATURE, DEGREES FAHRENHEIT
40 30 20 10 0 -10 -20 -30 -40 -50 -60
TEMPERATURE, DEGREES CENTIGRADE
4 -1 -7 -12 -18 -23 -29 -34 -40 -46 -51
0 10 20 30 40 50 60
DOWFROST, PERCENT BY WEIGHT

Verification of Flow Rates and Directions

Initially, using the flow indicating device, ensure that flow has been established in the collector loop.

The flow directions and flow rates should be checked for all pumps associated with the solar heating system. For each pump:

- note the purpose for the pump

Purpose for pump: primary loop circulating pump

- insure that all valves are in the positions required for normal operation of the system.

- with the pump operating, close the valve closest to the outlet of the pump and observe the pump outlet stagnation pressure.

Pump stagnation pressure _____ kPa

- slowly open the valve at the outlet of the pump and observe the pump outlet operating pressure. If this pressure is the same as the pressure recorded with the valve closed or the pressure drops as the valve is opened and then rises again to the previous pressure, an air lock or a restriction in the system should be suspected.

Pump outlet operating pressure _____ kPa

- measure the pump inlet pressure and compute the pressure rise across the pump.

Pump inlet pressure _____ kPa

Pump pressure rise _____ kPa

- using the characteristic curve for the pump, compute the flow rate.

Calculated flow rate _____ L/min

Flow rate specified by the manufacturer 8.6 L/min

Repeat the procedure for the secondary pump.

Purpose for pump: secondary circulating pump

Pump stagnation pressure _____ kPa

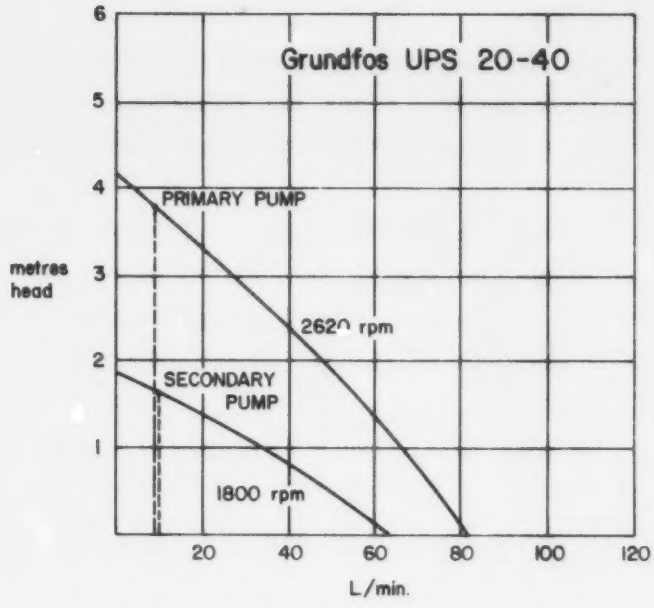
Pump outlet operating pressure _____ kPa

Pump inlet operating pressure _____ kPa

Pump pressure rise _____ kPa

Calculated flow rate _____ L/min

Flow rate specified by the manufacturer 10 L/min



PUMP PERFORMANCE CURVE

EQUATION TO CONVERT metres head TO kPa head:

metres head X $\frac{101\ kPa}{10{\cdot}34\ m}$ = kPa head

Collector Array Balancing Check

With the system operating on a sunny day, the collector array should be checked for proper connection and balancing. Automatic air bleed valves should also be checked for proper operation and setting.

- with a surface temperature measuring device, check the inlet and outlet temperatures from the collector array. If the temperature at the outlet of the array is not greater than the temperature at the inlet of the array, improper connection of the array may be suspected.

  Collector array inlet temperature _____ °C

  Collector array outlet temperature _____ °C

- check all automatic air bleed valves to insure that:

  - no air is present,
  - associated isolation valves are open,
  - protective caps are loosened to allow air to escape.

The remainder of this test need only be performed on systems which have collectors connected in parallel and use external headers.

- measure the temperature at the outlet of each individual collector. The outlet temperatures should all be within one degree Celsius.

Collector outlet temperatures

1. _____ °C
2. _____ °C
3. _____ °C
4. _____ °C
5. _____ °C
6. _____ °C

Control System Operation

The control system should be checked for proper operation. Due to the nature of the operation of a package solar heating system, the time required to observe the proper operation of the control system cannot be justified within this commissioning procedure. In lieu of actually observing its proper operation, it will be assessed on spot observations and on recordings of the control system run time meter.

- with the controls set for automatic operation, observe the solar storage temperature and determine, in light of the amount of solar radiation available, whether or not the system is performing properly.

- have the system installer record the date and time that the system is put into automatic operation and record the reading on the control system run time meter. If this data is not available, the reading taken during commissioning must be considered as the initial reading and a subsequent reading will be required at a later date. In either case, the two readings should be at least three days apart and a portion of the intervening time must have had weather suitable for the collection of solar energy.

  Readings taken by system installer (initial reading)

  Date _____ time _____

  Control system run time _____ hrs

- record the current reading (second reading)

  Date _____ time _____

  Control system run time _____ hrs

- calculate the total number of hours between the time the two readings were taken, and the total number of hours that the collector pump has operated during that time. The system should have operated between 10 and 60 percent of the total elapsed time, depending on weather conditions, time of year, load and other factors. If the system has not operated at all, or has operated continuously, a control system problem should be suspected.

Total elapsed time _____ hrs

Control system run time _____ hrs

Control system operating factor _____ %

Heat Exchanger Operation

The heat exchanger should be checked to ensure that it is properly connected.

- record the inlet and outlet temperatures on both sides of the heat exchanger. Ensure that the device is connected in a counterflow arrangement, that is, the hot connections of the two loops are close together and the cold connections of the two loops are close together.

Record:

Collector loop inlet temperature _____ ^{o}C

Collector loop outlet temperature _____ ^{o}C

Load side inlet temperature _____ ^{o}C

Load side outlet temperature _____ ^{o}C

OPERATIONAL MONITORING DOCUMENT

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL CL 5-6 - CLOSED LOOP

INDEX

1. General System Description

2. System Operation

3. Introduction to Operational Monitoring

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   - Monthly Operational Checklist
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     - System Pressures
     - General Overview
   - Semi-Annual Operational Schedule
     - Run Time
     - Fluid Quality
     - Preventative Maintenance

1. General System Description

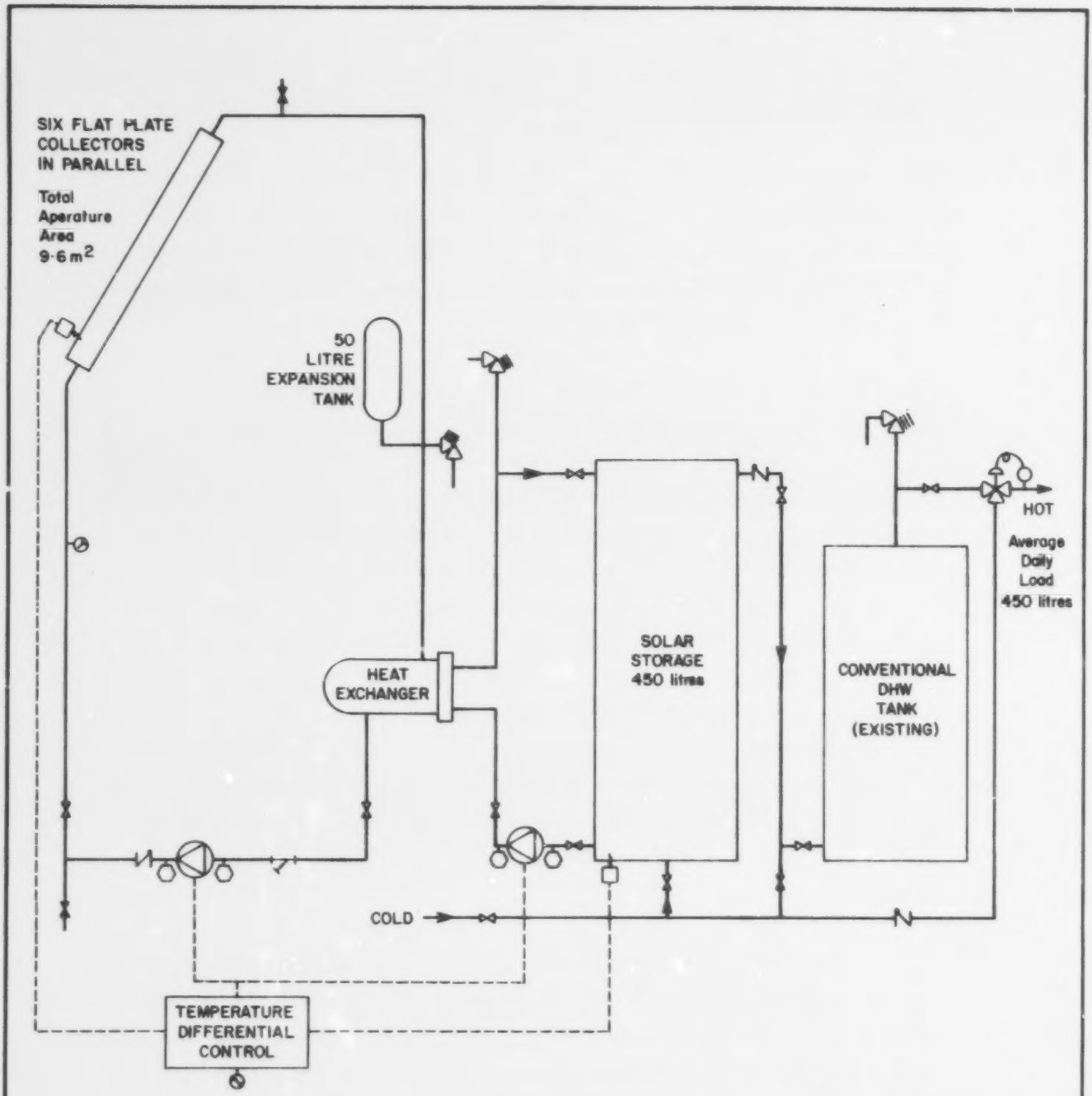
This domestic hot water package is designed for an average load of 450 liters of hot water per day. It will use solar energy to preheat cold water for any conventional DHW tank. Depending on your exact location and water demand, this model should decrease your electric water heating costs from forty to sixty-five percent.

Note the schematic of the solar hot water system. The system is made up of two major loops; the primary loop and the secondary loop.

The primary loop is a closed loop of piping containing glycol. The primary loop pump circulates the glycol through the collectors, where it is heated, and then through the heat exchanger, where the heat from the glycol is transferred to the water in the secondary loop. An expansion tank and pressure relief valve are in the primary loop to allow for expansion of the glycol if the temperature rises dramatically. A gate valve and strainer are upstream from the pump, and a gate valve and check valve are downstream. The gate valves are needed to isolate the pump from the rest of the system, if required. The check valve is to prevent back flow. Two gate valves; one at the top of the loop and the other at the bottom, are used to drain the glycol or to bleed off air. Their normal position is closed.

The secondary loop contains the water that is being heated. Cold water flows into the solar storage tank (flow is controlled by a gate valve). It then is pumped (again, the pump can be isolated by two gate valves) from the storage tank through the heat exchanger where it is heated by the glycol from the primary loop. It flows back into the solar storage tank. Note the pressure relief valve.

Hot water from the solar storage tank flows into the DHW tank. A check valve prevents back flow into the solar storage tank and gate valves control the flow. If the water in the tank is at a temperature less than $60^{\circ}C$, it is heated electrically to that temperature. If, for any reason, the solar system must be shut down, cold water can be directly brought into



LEGEND

- FLOW INDICATOR
- PETERSON PLUG
- RUN TIME METER

DATE	MARCH, 1982
DESIGNED	S.B.
DRAWN	G.B.
CHECKED	P.T.

Illustration Solar Manufacturing

Domestic Hot Water Package

Schematic with Instrumentation for Model CL 5-6 Closed Loop

SCALE	PROJECT NO.	DWG. NO.	REV.
N.T.S.	81-56	2	

SYSTEM "A" Figure 1-1

the electric heater by opening the normally closed gate valve. If the water coming out of the auxiliary heater is too hot (greater than 60°C), cold water is mixed in to lower the temperature.

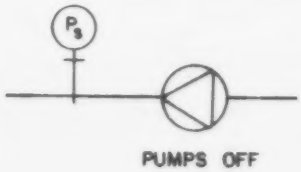
2. System Operation

The primary and secondary loop circulate if there is enough available solar energy. A temperature differential control turns the system on and off. The controller compares the temperature of the collector plates to the temperature of the water in the solar storage tank. If the collectors are 10°C warmer than the storage tank, the two pumps will be activated. When the differential drops down below 3°C, the pumps will be shut off.

The instrumentation is noted on the schematic. The instruments are needed to monitor the system to make sure it is operating correctly. There is a Peterson Plug before and after each pump to measure the pressure in, the pressure out and the static pressure. A run time meter is installed on the differential controller to keep track of the amount of time the system operates. Also, a flow indicator is situated in the primary flow loop.

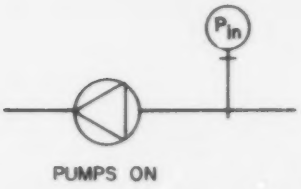
In order to follow the operational monitoring schedule, the following measurements must be understood:

- system static pressure:



The static pressure is the pressure of the liquid in the piping system with the pumps off. The static pressure will be measured in both the primary loop (glycol) and the secondary loop (water). The procedure is the same for both cases. With the pumps off, the pressure gauge just downstream of the pump measures the static pressure.

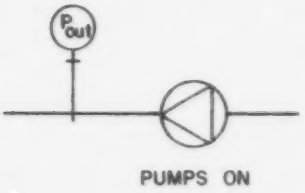
- inlet pump pressure:



The inlet pressure is the pressure of the liquid in the piping system just upstream of the pump when it is operating.

The inlet pressure will be measured in both the primary glycol loop and the secondary water loop. The procedure is the same for both cases. With the pumps on, measure the inlet pressure on the gauge just upstream from the pump.

- outlet pump pressure:



The outlet pressure is the pressure of the liquid in the piping system just downstream of the pump when it is operating.

The outlet pressure will be measured in both the primary glycol loop and the secondary water loop. The procedure is the same for both cases. With the pumps on, the pressure gauge downstream from the pump measures the outlet pressure.

- run time:

The run time meter attached to each controller clocks the time the system is operating. This information is used to ensure that the system is operating close to the expected amount of time.

3. Introduction to Operational Monitoring

The prime purpose of operational monitoring is to detect a decrease in the solar system performance. This is done by regularly comparing certain indicators, such as pressures and system run times with those specified in the design and commissioning process. A change in these indicators outside of the design range means that the system has an operational problem. Identifying operational problems or system breakdowns as soon as possible is important to reduce damage to the system, and will also maximize the energy output of the solar system. Early detection of problems will also increase the life of the system, and keep operating and maintenance costs to a minimum.

Checks of instrument readings and verifications of the operation or condition of component equipment are conducted on a monthly and semi-annual or yearly basis.

4. Operational Monitoring Procedures

Monthly Operational Checklist

To ensure that no major malfunction of the solar system has occurred, the following questions should be considered monthly. If the answer to any of the questions is "no", a problem has been detected. To determine the cause of the problem and the required action, see the Troubleshooting Guide.

(a) Pumps

1. If the weather is sunny, or partially sunny, are the pumps operating?
2. If there is no sun, are the pumps off?

(b) System Pressures

3. Is the system static pressure within the acceptable range?
   (acceptable range: primary loop 100 kPa to 140 kPa
   secondary loop 280 kPa to 400 kPa)
4. If the pumps are operating, is the change in pressure across each pump in the specified range? (low, high)
   (acceptable range: primary loop 36 kPa to 38 kPa
   secondary loop 14 kPa to 16 kPa)
5. If the pumps are operating, is the discharge pressure relatively constant for each pump? (maximum deviation = 1 kPa)

(c) General Overview

6. Does the status of all system alarms indicate normal system operation?
7. Have the pressure relief valves remained closed?
8. Are the vibration and noise levels normal?
9. Is the temperature of all mechanical equipment normal? (no overheating)

Semi-Annual Operational Schedule

Twice a year, in the spring and fall, a more detailed version of the "monthly checks" should be performed. This procedure will provide a closer examination of the system to check for possible problems. The checks should be done on a day when solar energy is available and the system is cycling. Use the following procedure:

(a) Run Time

For each control module, read and record the run time. Subtract the previous month's reading to find the monthly run time. Compare this with the expected value for the month. Being high or low may be a result of abnormal weather, but may also be an indication of problems.

Expected Run Time (in hours)	January	90
	February	120
	March	120
	April	180
	May	240
	June	240
	July	210
	August	210
	September	180
	October	150
	November	120
	December	90

(b) **Fluid Quality**

1. Measure the specific gravity of the glycol-water mixture using a hydrometer. The specific gravity of the mixture indicates the percentage of glycol and water which determines the freeze point of the solution. The specific gravity of the mixture must be greater than 1.0335 kg/L and less than 1.0345 kg/L at 25°C. If it is out of the acceptable range, alter it by adding more water or propylene glycol to make the specific gravity 1.034 kg/L.
2. Determine the pH factor (a measure of the acidity of the solution) of the mixture. In order to minimize corrosion, the pH of the solution must be greater than 8 and less than 10.

(c) Preventative Maintenance

- clean collector glazing where necessary,
- inspect collectors for the following:
    - weep holes filled with debris, insects, ice, etc.,
    - deterioration of the absorber plate in the form of discolouration or buckling,
    - permanent condensation on the underside of the collector glazing,
    - temperature variance: a collector that is noticeably cooler or warmer than the others indicates a flow blockage or imbalance,
- check mounting hardware security and caulking as well as flashing around roof penetrations,
- lubricate pumps, motors and control linkages as required,
- clean filters and strainers,
- cycle or operate valves to assure functioning.

TROUBLESHOOTING DOCUMENT

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL CL 5-6 - CLOSED LOOP

TROUBLESHOOTING GUIDE

Symptom	Source	Cause	Action
No hot water	Make-up water shut-off valve	Valve closed	Open valve.
	Auxiliary heater	Failed to activate	Check breaker or fuse. Check power to heater. Check fuel supply.
Hot water temperature too low	Hot water thermostat	Thermostat setting too low	Set thermostat higher.
	Auxiliary heater	Not functioning	Check breaker or fuse. Check and repair auxiliary heating unit and fuel supply.
	Temperature modulating valve	Faulty	Repair or replace.
		Temperature set too low	Reset.
Water temperature too high	Hot water thermostat	Thermostat setting too high	Reset.
		Thermostat out of calibration	Recalibrate.
	Temperature modulating valve	Faulty	Repair or replace.
		Temperature set too high	Reset.
Insufficient hot water to load, but solar system seems normal	Auxiliary heater	Auxiliary heater problems	Check auxiliary heater, wiring, gas, oil lines, burners, and set points.
	Valves	Isolation valves improperly closed	Set in proper positions.
	Temperature modulating valve	Improperly adjusted	Check adjustment and adjust as necessary.
		Faulty	Repair or replace.

Symptom	Source	Cause	Action
Drop in water pressure at both hot and cold outlets	Inlet water pressure	Inlet strainer clogged	Clean basket.
	Pressure reducing valve	Malfunctioning	Check for plugged ports, and proper operation. Clean, repair, or replace.
Drop in water pressure at hot outlets only	Valves	Valve improperly closed	Open manual valves. Check automatic valve operation. Repair or replace.
		Jammed check valve	Repair or replace.
	Strainers	Flow restriction	Check and clean.
System does not start or Pumps not running when solar energy available	Power supply	Control switch in "off" position	Turn to "auto" position.
		No power to pump	Check fuses or circuit breaker.
			Check wiring and connections.
		No power to controller	Check fuses or circuit breaker.
			Check wiring and connections.
	Pump	Pump seized	Try turning by hand. Repair or replace.
		Motor failure	Repair or replace.
	Controls	Control failure	Try on "manual". If pump runs, suspect control system (Refer to Troubleshooting Controls).
		Pressure cut offs activated	Rectify cause, reset.
		Temperature cut off activated	If tank temperature is below the high limit cut off, check the control system (Refer to Troubleshooting Controls).

Symptom	Source	Cause	Action
		Fault in control system	Check control system (Refer to Troubleshooting Controls).
		Electrical problem	Check line terminal voltage.
Pumps running when no solar energy available	Control system	Control set on "manual"	Set on "automatic".
		Fault in control system	Check control system. (Refer to Troubleshooting Controls).
Pump cycling excessively	Controls	Incorrect set points	Check set point.
		Fault in control system	Check control system. (Refer to Troubleshooting Controls).
System static pressure low	Charge pressure low	Fluid level low	See "Fluid level low"
	Expansion tank (Diaphram)	Bladder capacity exceeded or diaphram leaking	Inspect for fluid in air chamber. Replace expansion tank.
	Expansion tank (Standard)	Inadequate air space	Adjust liquid level.
		Air leak	Find and correct.
Fluid level low	Leak in system	Piping leak	Repair. Replace wet insulation.
		Leak from drain	Close drain tightly, add cap.
		Leak from air vent	Inspect, clean mechanism. Repair or replace.
	Pressure relief valve	Relief valve has expelled excess pressure	Find cause for excess pressure; correct. Recharge system to operating pressure.
System static pressure high	Controls	Overtemperature	Find cause. (Refer to Troubleshooting Controls).
	Fluid	System overfilled	Check level.

Symptom	Source	Cause	Action
	Expansion tank	Expansion tank is waterlogged	Check expansion tank liquid level. Check for air leak.
Pump discharge pressure fluctuating	Pump	Cavitation	Find source of air entry. Check for restriction on suction side, clean strainer.
Storage temperature decays during periods of no load	Insulation	Damaged or wet	Repair or replace.
	Check valve	Reverse thermosyphoning	Inspect check valve operation. Repair or replace.
Storage temp. remains high during high load, little solar	Valves	Isolation valves improperly closed	Set in proper position.
Poor solar energy collection	Collector array	Film on collector glazing	Check for dirt on glazing. Check for condensation and outgassing. Clean glazing.
		New source of shading	Check for new structures, growth of trees, etc.
		Flow rate	Check flow rate. Reset to specified flow.
			Check operation of automatic flow control valve. Repair or replace as necessary.
		Flow balance	Check balance of flow through collector banks. Rebalance as necessary.
			Check operation of automatic flow control valves. Repair or replace as necessary.
		Scale forming in collector tubes	Flush collector loop.

Symptom	Source	Cause	Action
	Piping	Insufficient or damaged insulation	Check condition and adequacy of insulation. Repair, replace or add additional insulation.
	Collector fluid	Antifreeze/water concentration in collector loop fluid is improper	Check fluid properties. Follow manufacturer's recommendations.
		Reverse thermosyphoning	Inspect check valve operation. Repair or replace.
	Controls	Out of calibration	(See "Troubleshooting Controls.")
Excessive vibration or noise in system	Pump	Cavitation	Check for air entry, check for restriction on pump suction side. Clean strainer.
		Bearings	Check for hot or worn bearings. Check bearing alignment.
		Impeller	Inspect for misaligned shaft. Repair or replace.
			Check balance of impeller. Clean, repair or replace.
	Piping	Entrapped air	Check automatic air vents. Vent manually. Force purge system, find and correct source of air entry.
		Supports	Check condition and adequacy of hangers. Repair hangers or install additional hangers.
Water hammer	Automatic valves	Open or close too fast	Install valves with slower action. Modify controls to slow valve action.

The following section of the diagnostic chart will be helpful if the pump operating pressures as defined in the operators manual, or the system ΔT (Temperature of fluid coming out of the collectors - Temperature of fluid going into collectors), are out of the specified range.

Symptom	Source	Cause	Action
Pump discharge pressure not in design range	If this condition is found carry out the following checks: 1. Check system static pressure and insure that it is in the proper range. 2. Using the pump inlet pressure and the pump discharge pressure, determine the pressure difference across the pump (ΔP).		
Symptom	**Source**	**Cause**	**Action**
ΔP high		Generally the result of a flow restriction of some type.	
	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with adjust flow as per commissioning procedure.
		Shut-off valves closed	Open.
		Automatic valves closed	Check controls, operation, and springs. Repair or replace.
	Check valve	Jammed	Repair or replace.
	Air vents	Faulty - causing air lock	Operate needle valve manually; check float control, inspect, clean, repair or replace.
	Collector	Passages clogged	Feel if some collectors hotter than others. Remove collector, backflush passages.
	Strainer	Flow restriction	Check and clean strainers.

Symptom	Source	Cause	Action
ΔP Low	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with, adjust flow as per commissioning procedure.
	Three-way valves	Internal leaking	Check and repair.
	Pump	Cavitating	Find source of air entry. Check for flow restriction on suction side, clean strainer.
		Mechanical failure	Check and repair.
ΔT low ΔP(s) normal	Collectors	Dirty	Clean surface.
		Insulation wet	Dry or replace insulation. Reseal collectors.
		Excessive condensation	Inspect seal, pipe gaskets, and weep holes. Repair.
	Pipe or tank insulation	Damaged, wet or missing	Repair or replace.
	Heat exchanger	Scaled up	Clean heat exchanger.
	Controls	Setting incorrect or drifting	Reset. (See "Troubleshooting Controls")
ΔT low ΔP(s) low	Flow control valves	Tampered with (opened)	Check seals on valves, if tampered with, adjust flow as per commissioning procedure.
	Three-way valves	Internal leaking	Repair.
	Controls	Incorrectly set	(See "Troubleshooting Controls")
ΔT high ΔP(s) normal	Controls	Incorrectly set	(See "Troubleshooting Controls")
ΔT high ΔP(s) low	Pump	Cavitation	Find source of air entry, correct, clean strainer, check for restriction on suction side.
		Impeller damage	Check stagnation pressure. Repair.
	Three-way valves	Internal leak	Check and repair.

Symptom	Source	Cause	Action
ΔT high ΔP high		Generally the result of a flow restriction of some type.	
	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with, adjust flow as per commissioning procedure.
		Shut-off valves closed	Open.
		Automatic valves closed	Check controls, operation, and springs. Repair or replace.
	Check valve	Jammed	Repair or replace.
	Air vents	Faulty - causing air lock	Operate needle valve manually; check float control, inspect, clean. Repair or replace.
	Collector	Passages clogged	Feel if some collectors hotter than others. Remove collector, backflush passages.
	Strainer	Flow restriction	Check and clean strainers.
Pump run time too high			(See "Pump(s) running when no solar energy available")
Pump run time too low			Check ΔT and ΔP(s) and refer to appropriate section, if cause not evident, refer to "System Diagnostic Procedures".

TROUBLESHOOTING SOLAR CONTROLS

In troubleshooting solar controls, it is important to use a logical and systematic approach to isolate and correct system faults. The following is the recommended procedure. This procedure is for variable resistance type controllers. For I.C. controllers which use variable voltage sensors, voltages are measured instead of resistances.

Differential Controller Checks

1. Check power supply to controller.

2. Check that all components are wired correctly to controller (according to manufacturer's specifications).

3. If the pump or valve does not work in the "manual" mode, disconnect it from the controller and apply rated voltage to its input wires at the controller.

    a. If it runs, the pump is all right - the problem is in the control system.

    b. No operation - the pump or valve is faulty or the interconnecting wiring or relay is faulty. Isolate the fault and repair or replace the defective component.

4. Check all sensors for:

    - proper location,
    - secure attachment with no corrosion build up,
    - proper wiring to controller.

5. Check each sensor for proper resistance by disconnecting it at the controller. If the measured resistances are as specified, the fault is a controller problem. Proceed to Step 8. If the measured resistances do not correspond to the specification value for the temperature of the sensor location, then:

   - the sensor is faulty,
   - the interconnecting wiring is faulty.

6. Disconnect sensor from wiring leading to the controller. Check the sensors resistance at this point. If the resistance is not to specification, replace the sensor.

7. If sensor is accurate, check for corrosion at all wiring connections. Clean, reconnect and remeasure resistance at the controller. If the measured resistance is still not correct, replace the wiring between the sensor and the controller.

8. Controller operational check.

   - switch off the electrical power to all pumps and/or control valves and make sure the controller is set for the recommended temperature differential;

   - replace the temperature sensors at the collector and the tank with variable resistors (variable resistors with readouts will simplify the procedure). The resistors can be connected to the sensor terminals at the controller;

   - from the temperature sensor characteristic curve, determine the resistance associated with 5°C absolute temperature;

   - dial this resistance into the variable resistor on the output to the tank sensor. Record the resistance;

- with the controller set in the automatic position, gradually change the resistance on the collector side until an output is measured at the controller output terminals (to pump or control valve). Record the indicated resistance;

- vary the resistance until there is no longer an output at the controller output terminals. Record the indicated resistance;

- reset the tank variable resistor for the resistance associated with a 15°C absolute temperature;

- repeat the above procedure determining the collector resistance to receive an output at the output terminal and the resistance to receive no output. Record both resistances;

- calculate the differential resistance and from the temperature sensor characteristic curve, determine the temperature differential;

- compare this with the original setting of differential temperature;

- if the two figures disagree substantially (more than ten percent), adjust the controller setting and repeat the above test.

9. Sensor Calibration Check

Preparation

1. Obtain a copy of the temperature sensor characteristic curve from the manufacturer (resistance vs. temperature).
2. Use a digital multimeter with an appropriate probe to determine as accurately as possible the temperature at the point the sensor is intended to sense.

Method

Determine the temperature at the point the sensor is intended to sense. These will likely be the temperature on the absorber plate in one of the collectors and the temperature in the lower third of the storage tank.

Measure with an ohm meter the resistance shown by the sensor. This should be done at two temperatures for each sensor, for example:

For collector sensors:

1. Cool Temperature - as early as possible in the morning, preferably on a cloudy day.
2. Hot Temperature - mid to late afternoon on a sunny day.

For storage tank sensors:

1. Cool Temperature - after a major draw of heat from storage to load on a cloudy day and before the auxiliary heat has replenished the draw (where applicable).
2. Hot Temperature - late on a sunny day before a major draw of heat or on a day when the load is reduced.

Compare the measured resistance with that shown on the manufacturer's table or graph for the appropriate temperature.

If the resistance varies from the expected value, the sensor or sensor lead connections may be corroded or the sensor may have been damaged by heat extremes. Check both and replace as necessary, then repeat the test.

Freeze Protection Controls

Thermal switch sensors are used for freeze protection of the collector loop on drain back systems or heat exchangers on closed loop systems.

The freeze protection set point should be at least 3°C (5°F) above the actual freezing point. Once the thermal switch set point is reached, the switch should de-activate the pump on drain back systems, causing the system to drain. In closed loop glycol systems, the freeze protection thermal switch circuit prevents the pump running due to controller failure.

Sensors used for freeze protection may be either the thermal switch type or variable resistance type.

Test Procedure for Thermal Switch Type

1. Connect the thermal switch to an ohm meter so you can see when it changes state. Seal the sensor along with a thermometer in a plastic bag. Place the bag into cool water and add ice for further cooling. When the sensor changes state, record the temperature and ohm meter reading. Slowly warm the water and sensor until it changes state again. Record the temperature and ohm meter reading. The first set of readings is the low temperature limit set point and the second is the temperature at which heat collection can restart.

2. After checking the thermal switch, connect it to the controller or pump circuit and retest by varying the temperature as described, and verify that the proper response occurs.

Test Procedure for Variable Resistance Types

1. If freeze protection circuit uses a thermistor, nickel wire or film as its sensor, then a variable resistor whose resistance range passes through that of the low temperature set point should be connected to the collector sensor inputs. A resistor with a value somewhat less than the collector freeze point should be connected to the storage input. With the appropriate load connected to the controller, connect the controller to the power input. The variable resistor should be varied above and below the freeze protection set point. Verify that the appropriate response occurs at the temperatures and resistance values specified by the manufacturer.

High Temperature Limit Protection

High temperature limit switches are used in solar systems either to protect collectors and storage tanks or as a secondary safeguard against failure of the mixing valve on the outlet to load.

The collectors are normally designed to withstand the stagnation temperatures and thermal shock associated with this. Control logic should be set up so that the temperature limit switch will not inhibit the initial start up of the collector loop pump, but will activate if, after a reasonable length of time, the collector temperature has not fallen.

For closed loop glycol systems, the high temperature limit or control logic may be used to divert flow to a heat purge coil.

High Temperature Protection for Storage Tanks

High temperature limit switches are used to protect storage tanks from over temperature conditions. In some cases, a tank temperature limit can serve as a secondary protection against scalding temperatures being delivered to the load if the mixing valve fails.

High Temperature Limit Switch Checkout

The checkout procedure is similar to that for freeze protection. The switch or sensor is immersed in hot water, which is heated until the device activates and then cooled until it reverses. The temperatures and resistances for these points are recorded and checked against the specification.

GENERAL SYSTEM DIAGNOSTIC PROCEDURE

The performance of a solar system depends on the interaction of all system components, outside conditions, and the load imposed on the system.

There are cases in which a general decrease in the performance of a system is indicated by a decrease in system operating time, temperature differences, measured energy collected, or by an increase in the required auxiliary energy. In some cases, the particular problem cannot be isolated by the operator. The following is a general diagnostic procedure which can, in most cases, isolate the causes.

Carrying out this procedure requires some knowledge of solar systems and a number of portable instruments; therefore, a troubleshooting technician or engineer may be required.

1. The first step is a visual inspection of the system paying special attention to such items as completeness and condition of insulation and whether the collectors are clean and free of new shading.

2. Verifying flow rates.

   The operating flow rates in each loop should be checked by the means provided. This may be by using pump differential pressures or by reading a flow meter if one is installed in the particular loop. (See commissioning procedure.)

3. If the flow rate in any loop in the system is lower than specified the flow, restriction can be isolated by checking the pressures at the monitoring points provided in the system and comparing these with the commissioned values.

4. If the flow rates in all points of all loops are as specified, check the fluid temperatures at each monitoring point on a clear sunny day.

5. Verify the flow balance through the collector banks.

   The face temperature of each collector should be checked by feel or, preferably, with a pyrometer. Collectors that are significantly warmer or cooler than their neighbours indicate flow blockages and stagnation or high flows respectively.

   It is a good idea to check the bank temperature balance by the method shown in the commissioning procedure.

6. Verify the effectiveness of the heat exchanger as in the commissioning procedure. A reduced effectiveness could indicate scaling of the heat exchanger surfaces.

7. Perform the preliminary thermal performance test as shown in the commissioning procedure and compare the efficiency with the commissioned values. This will detect degradation of the collectors' performance.

8. Check the calibration of the control system as described in "Troubleshooting Solar Controls."

If satisfied that the operating characteristics of the system are normal, investigate the non-operating features.

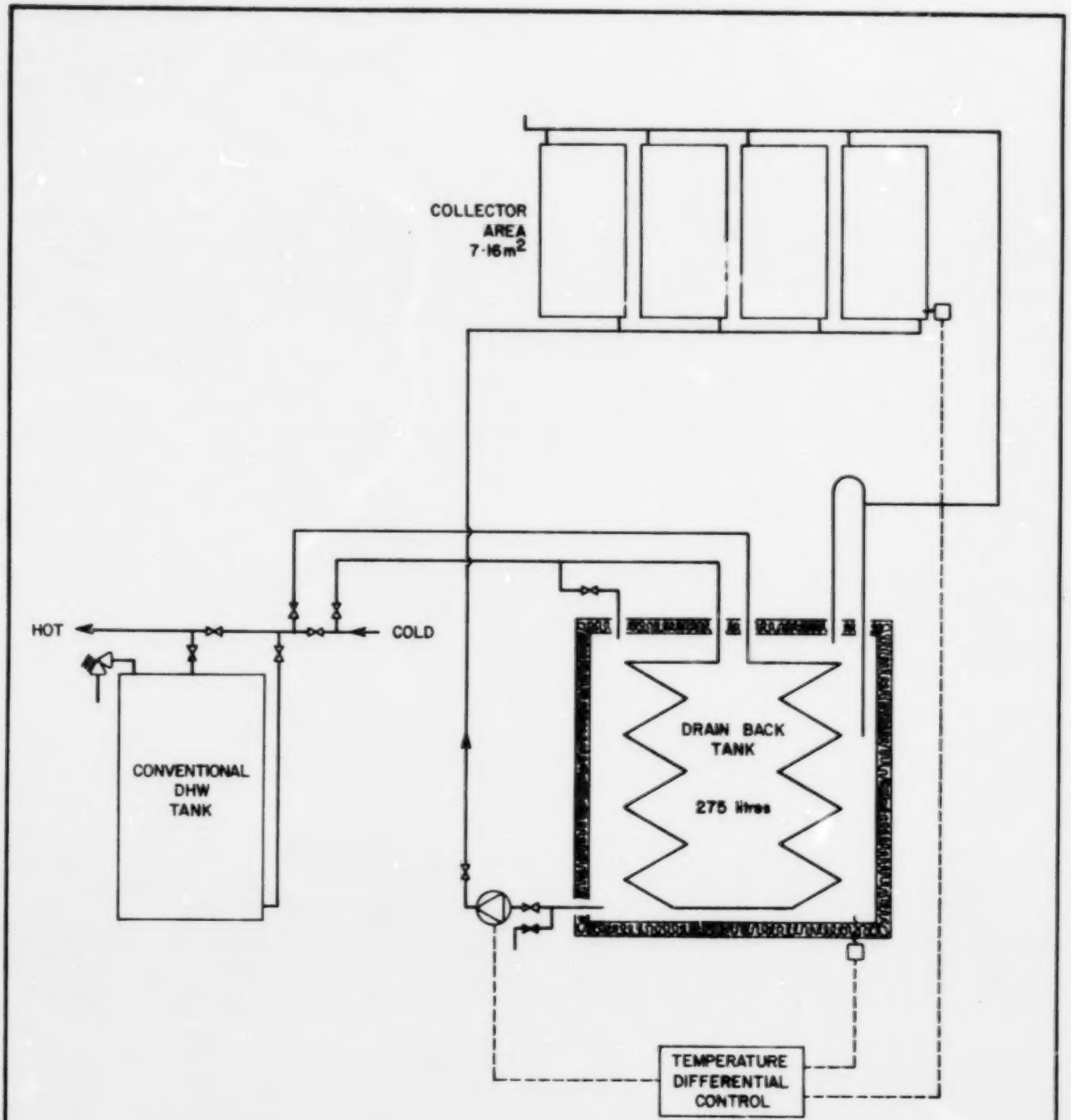
9. Isolate the system from load and bring the storage temperatures up during the day. Read the storage temperature at nightfall and shut off the system. Check the storage temperature in the morning. If the storage temperature has dropped significantly, suspect damaged or wet insulation, or reverse thermosyphoning (usually the result of a faulty check valve).

EXAMPLE SYSTEM "B"

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL DB10-4 - DRAINBACK

This system is a simple domestic hot water or process hot water heating system with a drainback water collection loop.

This system is to be used with a conventional Domestic Hot Water tank.



DATE	DECEMBER 1981	
DESIGNED	G.O.	
DRAWN	G.B.	
CHECKED	A.M.	

Illustration Solar Manufacturing

Domestic Hot Water Package

Schematic
Model DB 10-4 Drain Back

SCALE	PROJECT NO.	DWG. NO.	REV.
N.T.S.	81-20	1	

SYSTEM "B"

SELECTED INSTRUMENTATION

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL DB10-4 - DRAIN BACK

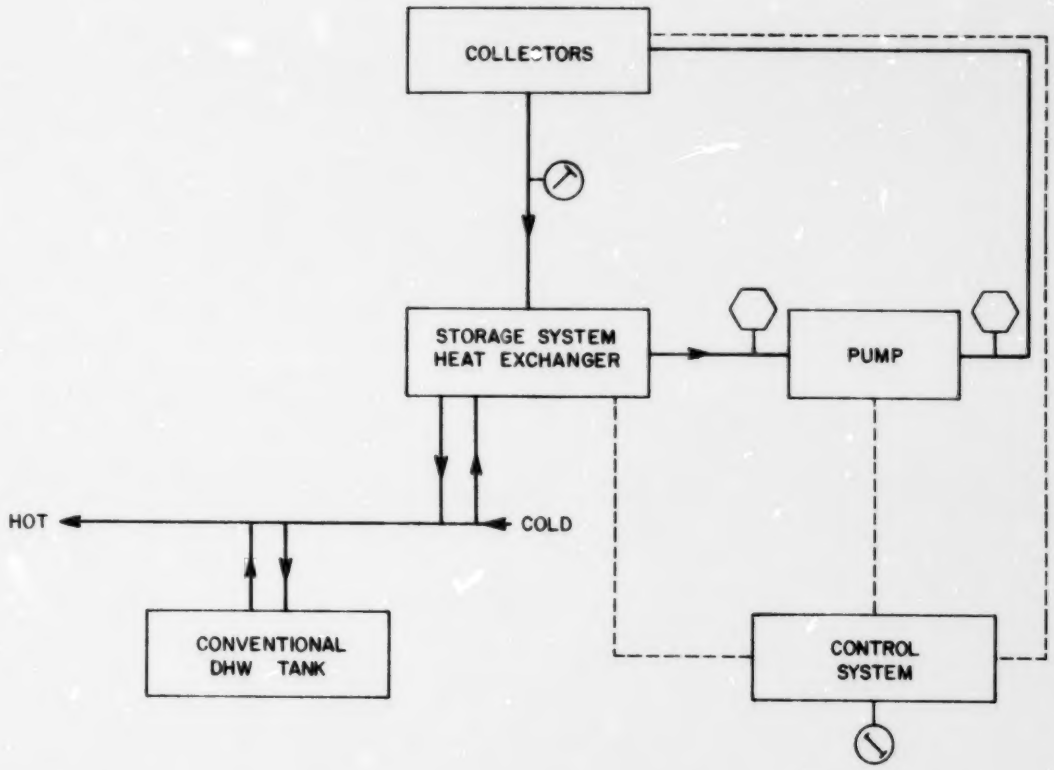
List of Required Instrumentation

1. Two Peterson Plugs, part number 110, to be installed in elbows on the inlet and outlet of each pump.

2. One Bach Simpson Number 1357 ETIF elapsed-time meter to be installed to monitor the control system.

3. One flow indicator to be installed in the collector loop.

4. One Winters pressure gauge with a range from 0 to 100 kPa to be used with a Model 500 Peterson Plug.



LEGEND

PETERSON PLUG

FLOW INDICATOR

RUN TIME METER

SYSTEM B
Illustration Solar Manufacturing
Domestic Hot Water Package
Model DB 10-4 Drain Back

Modular Representation with Instrumentation

COMMISSIONING DOCUMENT

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL DB10-4 - DRAIN BACK

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1. General Introduction to the Commissioning Document

2. System Inspection

3. System Tests
   - System Pressure Test
   - Verification of Flow Rates and Directions
   - Collector Array Balancing Check
   - Verification of System Drain Back
   - Control System Operation
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1. General Introduction to the Commissioning Document

The commissioning procedure is divided into two major sections. The first section details the inspections necessary to insure that the system is ready for commissioning. This includes checking for the instruments and test points required to carry out the commissioning procedures.

The second section is divided into a number of discrete tests. The performance and successful completion of these tests should insure that the installed system in general meets the manufacturer's design specifications. In addition to the installed instrumentation and test points, the commissioning contractor will require the following system information and instrumentation:

System layout drawings and installation instructions

Pump performance curves

An accurate electronic thermometer suitable for measuring pipe surface temperatures

A Winters pressure gauge with a range from 0 to 100 kPa

A device for measuring antifreeze density

A device for measuring antifreeze pH

2. System Inspection

Carry out a general inspection of the system to insure that the system is complete and that all system components have been properly installed. This visual inspection should include:

A check of all plumbing connections to ensure that collectors, pumps, heat exchangers and other components have not been connected in a reverse direction.

A check to insure that all safety equipment such as temperature and pressure relief valves are present and have been installed in the correct manner. For systems requiring a non-toxic working fluid, check to insure that an appropriate label has been attached to the fill valve warning that only non-toxic fluid must be added.

A check to insure that all pipes are adequately sloped, at least 1 in 48, to insure that complete draining of the system is possible.

A check of all pipe insulation to insure that the correct amount has been installed and that it is adequately secured and protected against water damage and ultraviolet deterioration.

A check to insure that all roof penetrations are adequately sealed.

A check of all wiring, both 110 volt and control wiring, to insure that it meets applicable electrical codes and that it is properly fastened to protect it against mechanical damage.

A check to insure that all instrumentation and test points required for carrying out the commissioning procedure have been installed. This includes the control system run time meter, a flow indicating device and Peterson Plugs at the inlet and outlet of each pump.

3. System Tests

System Pressure Test

Pressurized systems should be pressure tested to the pressure specified by the manufacturer of the system. The specified pressure must be at least equal to the maximum pressure to which it may be subjected in service.

Specified pressure for primary loop pressure test 100 kPa

- completely fill the system with the proper working fluid.

- pressurize the system to the specified pressure and visually inspect for leaks.

- keep the system pressurized for a period of at least fifteen minutes. A pressure drop over this period, without a visual sign of leakage, could indicate an internal leak such as in a heat exchanger.

Fifteen minute test pressure used _____ kPa

Verification of Flow Rates and Directions

Initially, using the flow indicating device, ensure that flow has been established in the collector loop.

The flow directions and flow rates should be checked for all pumps associated with the solar heating system. For each pump:

- note the purpose for the pump.

Purpose for pump: primary loop circulating pump

- insure that all valves are in the positions required for normal operation of the system.

- with the pump operating, close the valve closest to the outlet of the pump and observe the pump outlet stagnation pressure.

Pump stagnation pressure _____ kPa

- slowly open the valve at the outlet of the pump and observe the pump outlet operating pressure. If this pressure is the same as the pressure recorded with the valve closed or the pressure drops as the valve is opened and then rises again to the previous pressure, an air lock or a restriction in the system should be suspected.

Pump outlet operating pressure _____ kPa

- measure the pump inlet pressure and compute the pressure rise across the pump.

Pump inlet pressure _____ kPa

Pump pressure rise _____ kPa

- using the characteristic curve for the pump, compute the flow rate.

Calculated flow rate _____ L/min

Flow rate specified by the manufacturer ____6____ L/min

Collector Array Balancing Check

With the system operating on a sunny day, the collector array should be checked for proper connection and balancing. Automatic air bleed valves should also be checked for proper operation and setting.

- with a surface temperature measuring device, check the inlet and outlet temperatures from the collector array. If the temperature at the outlet of the array is not greater than the temperature at the inlet of the array, improper connection of the array may be suspected.

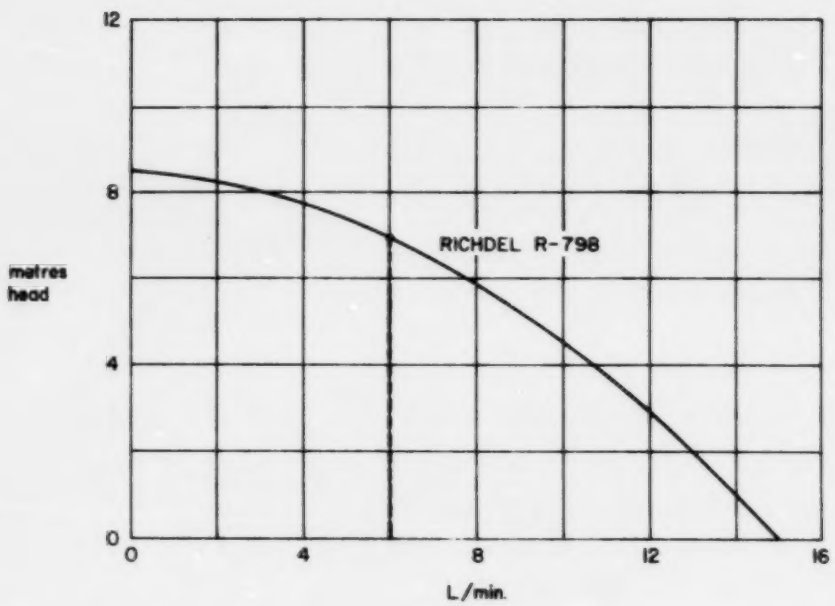
Collector array inlet temperature _____ °C

Collector array outlet temperature _____ °C

- check all automatic air bleed valves to insure that:

  - no air is present,
  - associated isolation valves are open,
  - protective caps are loosened to allow air to escape.

The remainder of this test need only be performed on systems which have collectors connected in parallel and use external headers.



PUMP PERFORMANCE CURVE

Equation to convert
metres head to kPa head:

metres head X $\frac{101\ kPa}{10{\cdot}34m}$ = kPa head

- measure the temperature at the outlet of each individual collector. The outlet temperatures should all be within one degree Celsius.

Collector outlet temperatures

1. _____ °C
2. _____ °C
3. _____ °C
4. _____ °C

Verification of System Drain Back

It is important to insure that drain back systems drain quickly and completely when required.

Turn the controller to the off position when the system is filled and circulating and measure the time required for the system to drain completely.

If the actual liquid level in the drain back tank can not be seen, draining of the system will have to be detected by sound. Complete drain back should occur within three minutes.

Drain back time _____ min.

Control System Operation

The control system should be checked for proper operation. Due to the nature of the operation of a package solar heating system, the time required to observe the proper operation of the control system cannot be justified within this commissioning procedure. In lieu of actually observing its proper operation, it will be assessed on spot observations and on recordings of the control system run time meter.

- with the controls set for automatic operation, observe the solar storage temperature and determine, in light of the amount of solar radiation available, whether or not the system is performing properly.

- have the system installer record the date and time that the system is put into automatic operation and record the reading on the control system run time meter. If this data is not available, the reading taken during commissioning must be considered as the initial reading and a subsequent reading will be required at a later date. In either case, the two readings should be at least three days apart and a portion of the intervening time must have had weather suitable for the collection of solar energy.

  Readings taken by system installer (initial reading)

  Date _____ time _____

  Control system run time _____ hrs

- record the current reading (second reading)

  Date _____ time _____

  Control system run time _____ hrs

- calculate the total number of hours between the time the two readings were taken, and the total number of hours that the collector pump has operated during that time. The system should have operated between 10 and 60 percent of the total elapsed time, depending on weather conditions, time of year, load and other factors. If the system has not operated at all, or has operated continuously, a control system problem should be suspected.

Total elapsed time _____ hrs

Control system run time _____ hrs

Control system operating factor _____ %

Heat Exchanger Operation

The heat exchanger should be checked to ensure that it is properly connected.

Record:

Load side inlet temperature _____ °C

Load side outlet temperature _____ °C

Solar tank storage temperature _____ °C

OPERATIONAL MONITORING DOCUMENT

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL DB10-4 - DRAIN BACK

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     - Fluid Quality
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1. General System Description

This solar package is designed to heat approximately 400 liters of water per day. This hot water will enter the conventional DHW tank where, if required, it will be heated to 40°C. By utilizing solar energy to preheat the water, the heating cost will be reduced by approximately fifty per cent.

Note the schematic of the solar hot water system. The system is made up of two major loops; the primary loop and the secondary loop.

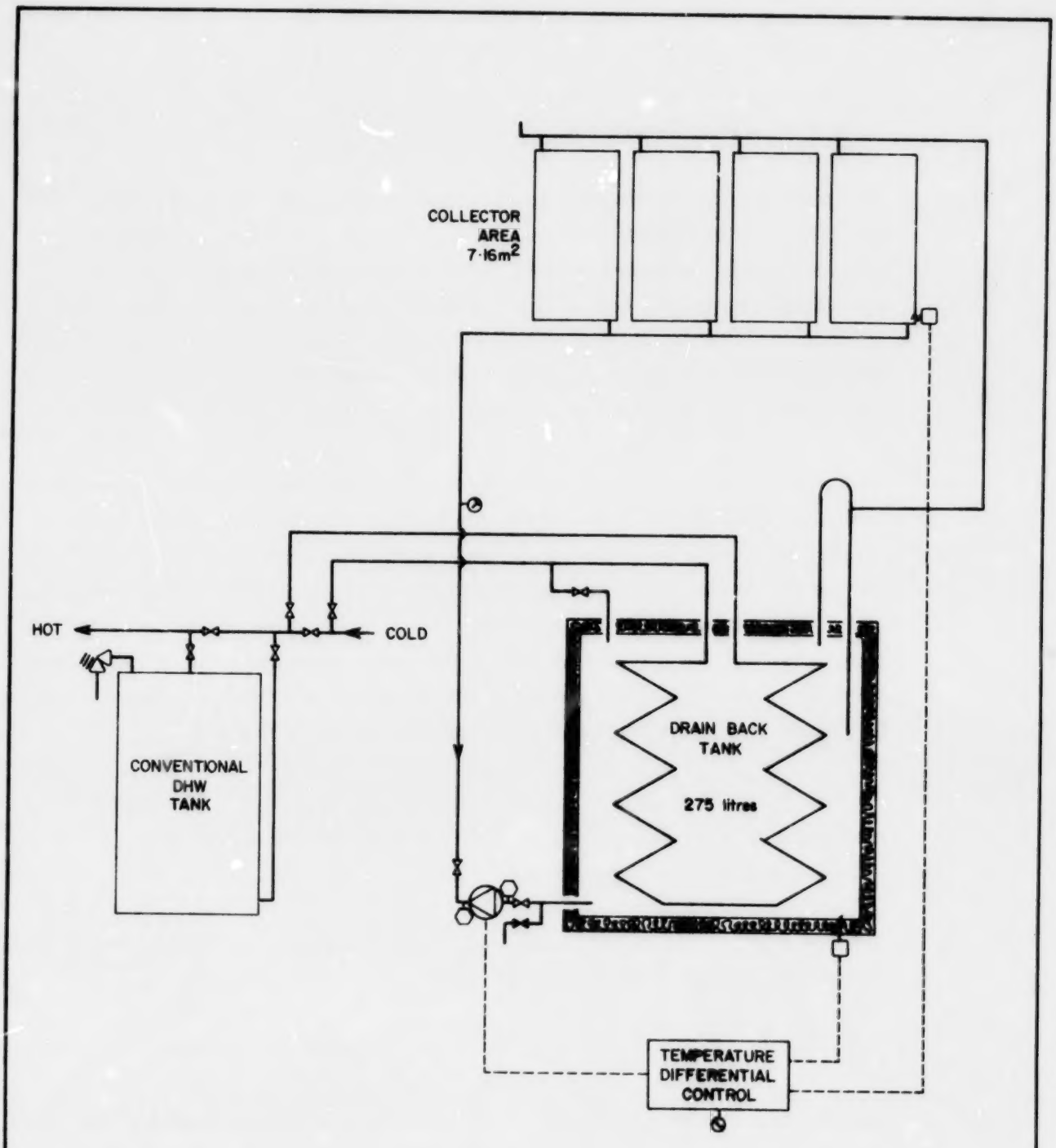
The primary loop is a drain back system containing treated water. When the pump is operating, the water circulates through the collectors where it is heated, and then through the drain back tank. The heat from the water is transferred to the water in the secondary loop which is piped through the tank. When the pump is not operating, the treated water drains back into the tank. Four gate valves are utilized in the loop. Two are used to isolate the pump from the rest of the system. The other two are normally closed - one can be opened to fill the tank, the other can be opened to drain it.

The secondary loop contains the water that is being heated. Cold water is piped through the drain back tank which acts as an internal heat exchanger. Flow is controlled by a gate valve.

The preheated water is then heated up to the required temperature in the conventional DHW tank.

2. System Operation

The primary and secondary loop circulate if there is enough available solar energy. A temperature differential control turns the system on and off. The controller compares the temperature of the collector plates to the temperature of the water in the drain back tank. If the collectors are 8°C warmer than the water in the tank, the pumps will be activated. When the differential drops down below 2°C, the pumps will be shut off.



LEGEND

- FLOW INDICATOR
- PETERSON PLUG
- RUN TIME METER

DATE	DECEMBER, 1981
DESIGNED	G. O.
DRAWN	G. B.
CHECKED	A.M.

Illustration Solar Manufacturing

Domestic Hot Water Package

Schematic with Instrumentation
Model DB 10-4 Drain Back

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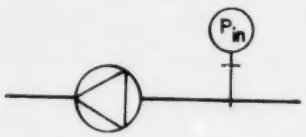
SYSTEM "B" Figure 1d

The instrumentation is noted on the schematic. The instruments are needed to monitor the system to make sure it is operating correctly. There is a Peterson Plug before and after the pump to measure the pressure in and the pressure out. There is also a run time meter on the control system. A flow indicator is situated in the primary flow loop.

In order to follow the operational monitoring schedule, the following measurements must be understood.

- inlet pump pressure:

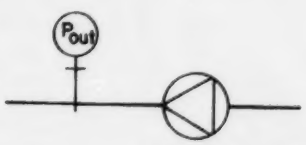


PUMP ON

The inlet pressure is the pressure of the liquid in the piping system just upstream of the pump when it is operating.

The inlet pressure will be measured in the primary glycol loop. With the pump on, measure the inlet pressure on the gauge just upstream from the pump.

- outlet pump pressure:



PUMP ON

The outlet pressure is the pressure of the liquid in the piping system just downstream of the pump when it is operating.

The outlet pressure will be measured in the primary glycol loop. With the pump on, the pressure gauge downstream from the pump measures the outlet pressure.

- run time: The run time meter attached to each controller clocks the time the system is operating. This information is used to ensure that the system is operating close to the expected amount of time.

3. Introduction to Operational Monitoring

The prime purpose of operational monitoring is to detect a decrease in the solar system performance. This is done by regularly comparing certain indicators, such as pressures and system run times with those specified in the design and commissioning process. A change in these indicators outside of the design range means that the system has an operational problem. Identifying operational problems or system breakdowns as soon as possible is important to reduce damage to the system, and will also maximize the energy output of the solar system. Early detection of problems will also increase the life of the system, and keep operating and maintenance costs to a minimum.

Checks of instrument readings and verifications of the operation or condition of component equipment are conducted on a monthly and semi-annual or yearly basis.

4. Operational Monitoring Procedures

Monthly Operational Checklist

To ensure that no major malfunction of the solar system has occurred, the following questions should be considered monthly. If the answer to any of the questions is "no", a problem has been detected. To determine the cause of the problem and the required action, see the Troubleshooting Guide.

(a) Pump

1. If the weather is sunny, or partially sunny, is the pump operating?
2. If there is no sun, is the pump off?

(b) System Pressures

3. If the pump is operating, is the change in pressure across the pump in the specified range? (low, high)
   (acceptable range: 55 kPa to 70 kPa)
4. If the pump is operating, is the discharge pressure relatively constant? (maximum deviation = 3 kPa)

(c) Fluid Level

5. If the system is not operating, is the fluid level in the drain down tank within the acceptable range? (acceptable level range within 2 cm of marked line)

(d) General Overview

6. Does the status of all system alarms indicate normal system operation.
7. Have the pressure relief valves remained closed?
8. Are the vibration and noise levels normal?
9. Is the temperature of all mechanical equipment normal? (no overheating)

Semi-Annual Operational Schedule

Twice a year, in the spring and fall, a more detailed version of the "monthly checks" should be performed. This procedure will provide a closer examination of the system to check for possible problems. The checks should be done on a day when solar energy is available and the system is cycling. Use the following procedure:

(a) Run Time

For each control module, read and record the run time. Subtract the previous month's reading to find the monthly run time. Compare this with the expected value for the month. Being high or low may be a result of abnormal weather, but may also be an indication of problems.

Expected Run Time (in hours)	January	90
	February	120
	March	120
	April	180
	May	240
	June	240
	July	210
	August	210
	September	180
	October	150
	November	120
	December	90

(b) Fluid Quality

To control the entry of corrosion causing oxygen into the water of the collector loop, an oil film is used on the top of the water in the drain back tank. Check the oil film thickness and replenish, if necessary.

(c) Drain Time

Manually stop the pump and measure the time taken for the fluid to completely drain. It should drain in less than 3 minutes.

(d) Preventative Maintenance

- clean collector glazing where necessary,
- inspect collectors for the following:
    - weep holes filled with debris, insects, ice, etc.,
    - deterioration of the absorber plate in the form of discolouration or buckling,
    - permanent condensation on the underside of the collector glazing,
    - temperature variance: a collector that is noticeably cooler or warmer than the others indicates a flow blockage or imbalance,
- check mounting hardware security and caulking as well as flashing around roof penetrations,
- lubricate pump, motor and control linkage as required,
- clean filters and strainers,
- cycle or operate valves to assure functioning.

TROUBLESHOOTING DOCUMENT

ILLUSTRATION SOLAR MANUFACTURING
DOMESTIC HOT WATER PACKAGE
MODEL DB10-4 - DRAIN BACK

TROUBLESHOOTING GUIDE

Symptom	Source	Cause	Action
No hot water	Make-up water shut-off valve	Valve closed	Open valve.
	Auxiliary heater	Failed to activate	Check breaker or fuse. Check power to heater. Check fuel supply.
Hot water temperature too low	Hot water thermostat	Thermostat setting too low	Set thermostat higher.
	Auxiliary heater	Not functioning	Check breaker or fuse. Check and repair auxiliary heating unit and fuel supply.
	Temperature modulating valve	Faulty	Repair or replace.
		Temperature set too low	Reset.
Water temperature too high	Hot water thermostat	Thermostat setting too high	Reset.
		Thermostat out of calibration	Recalibrate.
	Temperature modulating valve	Faulty	Repair or replace.
		Temperature set too high	Reset.
Insufficient hot water to load, but solar system seems normal	Auxiliary heater	Auxiliary heater problems	Check auxiliary heater, wiring, gas, oil lines, burners, and set points.
	Valves	Isolation valves improperly closed	Set in proper positions.
	Temperature modulating valve	Improperly adjusted	Check adjustment and adjust as necessary.
		Faulty	Repair or replace.

Symptom	Source	Cause	Action
Drop in water pressure at both hot and cold outlets	Inlet water pressure	Inlet strainer clogged	Clean basket.
	Pressure reducing valve	Malfunctioning	Check for plugged ports, and proper operation. Clean, repair, or replace.
Drop in water pressure at hot outlets only	Valves	Valve improperly closed	Open manual valves. Check automatic valve operation. Repair or replace.
		Jammed check valve	Repair or replace.
	Strainers	Flow restriction	Check and clean.
System does not start or Pump not running when solar energy available	Power supply	Control switch in "off" position	Turn to "auto" position.
		No power to pump	Check fuses or circuit breaker.
			Check wiring and connections.
		No power to controller	Check fuses or circuit breaker.
			Check wiring and connections.
	Pump	Pump seized	Try turning by hand. Repair or replace.
		Motor failure	Repair or replace.
	Controls	Control failure	Try on "manual". If pump runs, suspect control system (Refer to Troubleshooting Controls).
		Pressure cut offs activated	Rectify cause, reset.
		Temperature cut off activated	If tank temperature is below the high limit cut off, check the control system (Refer to Troubleshooting Controls).

Symptom	Source	Cause	Action
		Fault in control system	Check control system (Refer to Troubleshooting Controls).
		Electrical problem	Check line terminal voltage.
Pump running when no solar energy available	Control system	Control set on "manual"	Set on "automatic".
Pump cycling excessively	Controls	Incorrect set points	Check set point.
		Fault in control system	Check control system. (Refer to Troubleshooting Controls).
Fluid level low	Leak in system	Piping leak	Repair. Replace wet insulation.
		Leak from drain	Close drain tightly, add cap.
		Leak from air vent	Inspect, clean mechanism. Repair or replace.
	Pressure relief valve	Relief valve has expelled excess pressure	Find cause for excess pressure; correct. Recharge system to operating pressure.
Pump discharge pressure fluctuating	Pump	Cavitation	Find source of air entry, check for restriction on suction side, clean strainer.
System does not drain	Vacuum breaker	Damaged	Replace.
		Frozen	Thaw and protect from freezing.
	Piping	Piping not sloped adequately	Correct.
		Vent tube blocked	Check and clear.
	Controls	Control and sensor fault	(See "Troubleshooting Controls")
	Solenoid or motorized valve	Actuator defective	Replace.
		No power to actuator	Check wiring.
		Valve sticks	Repair or replace valve.

Symptom	Source	Cause	Action
System will not fill with pump running	Pump	Cavitation	Check for air entry, check for restriction on pump suction side, clean strainer. Check for low fluid level in drain back tank.
System drains continuously with pump running	Drain down valve will not close	Actuator defective	Replace.
		Power	Check wiring.
		Valve sticks	Repair or replace valve.
	Freeze protection thermal switch	Set point drift	Reset or replace.
		Defective	Replace.
		Loose contacts	Reconnect.
	Control sensors	Out of calibration	Recalibrate.
		Defective	Replace.
Pressure does not drop when system filled	Piping	Leak in pipes causes break in syphon	Find and seal.
		Major flow restriction in system	Check position of all valves.
	Vacuum breaker	Faulty	Replace.
		Frozen	Thaw and protect from freezing.
	Fluid	Leak has reduced fluid level - no circulation achieved	Seal leak; refill system.
	Pump	Impeller fouled or damaged to point that pump cannot overcome static head	Clean or repair pump.
Storage temperature decays during periods of no load	Insulation	Damaged or wet	Repair or replace.
	Check valve	Reverse thermosyphoning	Inspect check valve operation. Repair or replace.

Symptom	Source	Cause	Action
Storage temp remains high during high load, little solar	Valves	Isolation valves improperly closed	Set in proper position.
Poor solar energy collection	Collector array	Film on collector glazing	Check for dirt on glazing. Check for condensation and outgassing. Clean glazing.
		New source of shading	Check for new structures, growth of trees, etc.
		Flow rate	Check flow rate. Reset to specified flow.
			Check operation of automatic flow control valve. Repair or replace as necessary.
		Flow balance	Check balance of flow through collector banks. Rebalance as necessary.
			Check operation of automatic flow control valves. Repair or replace as necessary.
		Scale forming in collector tubes	Flush collector loop.
	Piping	Insufficient or damaged insulation	Check condition and adequacy of insulation. Repair, replace or add additional insulation.
	Collector fluid	Reverse thermosyphoning	Inspect check valve operation. Repair or replace.
	Controls	Out of calibration	(See "Troubleshooting Controls.")

Symptom	Source	Cause	Action
Excessive vibration or noise in system	Pump	Cavitation	Check for air entry, check for restriction on pump suction side. Clean strainer.
		Bearings	Check for hot or worn bearings. Check bearing alignment.
		Impeller	Inspect for misaligned shaft. Repair or replace.
			Check balance of impeller. Clean, repair or replace.
	Piping	Entrapped air	Check automatic air vents. Vent manually. Force purge system, find and correct source of air entry.
		Supports	Check condition and adequacy of hangers. Repair hangers or install additional hangers.
Water hammer	Automatic valves	Open or close too fast	Install valves with slower action. Modify controls to slow valve action.

The following section of the diagnostic chart will be helpful if the pump operating pressures as defined in the operator's manual, or the system ΔT (Temperature of fluid coming out of the collectors - Temperature of fluid going into collectors), are out of the specified range

Pump discharge pressure not in design range	If this condition is found carry out the following checks: 1. Check system static pressure and insure that it is in the proper range. 2. Using the pump inlet pressure and the pump discharge pressure, determine the pressure difference across the pump (ΔP).

Symptom	Source	Cause	Action
ΔP high		Generally the result of a flow restriction of some type	
	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with adjust flow as per commissioning procedure.
		Shut-off valves closed	Open.
		Automatic valves closed	Check controls, operation, and springs. Repair or replace.
	Check valve	Jammed	Repair or replace.
	Air vents	Faulty - causing air lock	Operate needle valve manually; check float control, inspect, clean, repair or replace.
	Collector	Passages clogged	Feel if some collectors hotter than others. Remove collector, backflush passages.
	Strainer	Flow restriction	Check and clean strainers.
ΔP Low	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with, adjust flow as per commissioning procedure.
	Pump	Cavitating	Find source of air entry. Check for flow restriction on suction side, clean strainer.
		Mechanical failure	Check and repair.

Symptom	Source	Cause	Action
ΔT low ΔP(s) normal	Collectors	Dirty	Clean surface.
		Insulation wet	Dry or replace insulation. Reseal collectors.
		Excessive condensation	Inspect seal, pipe gaskets, and weep holes. Repair.
	Pipe or tank insulation	Damaged, wet or missing	Repair or replace.
	Heat exchanger	Scaled up	Clean heat exchanger.
	Controls	Setting incorrect or drifting	Reset. (See "Troubleshooting Controls")
ΔT low ΔP(s) low	Flow control valves	Tampered with (opened)	Check seals on valves, if tampered with, adjust flow as per commissioning procedure.
	Three-way valves	Internal leaking	Repair.
	Controls	Incorrectly set	(See "Troubleshooting Controls")
ΔT high ΔP(s) normal	Controls	Incorrectly set	(See "Troubleshooting Controls")
ΔT high ΔP(s) low	Pump	Cavitation	Find source of air entry, correct, clean strainer, check for restriction on suction side.
		Impeller damage	Check stagnation pressure. Repair.
	Three-way valves	Internal leak	Check and repair.

Symptom	Source	Cause	Action
ΔT high ΔP high		Generally the result of a flow restriction of some type	
	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with, adjust flow as per commissioning procedure.
		Shut-off valves closed	Open.
		Automatic valves closed	Check controls, operation, and springs. Repair or replace.
	Check valve	Jammed	Repair or replace.
	Air vents	Faulty - causing air lock	Operate needle valve manually; check float control, inspect, clean. Repair or replace.
	Collector	Passages clogged	Feel if some collectors hotter than others. Remove collector, backflush passages.
	Strainer	Flow restriction	Check and clean strainers.
Pump run time too high			(See "Pump(s) running when no solar energy available")
Pump run time too low			Check ΔT and ΔP(s) and refer to appropriate section, if cause not evident, refer to "System Diagnostic Procedures".

TROUBLESHOOTING SOLAR CONTROLS

In troubleshooting solar controls, it is important to use a logical and systematic approach to isolate and to correct system faults. The following is the recommended procedure. This procedure is for variable resistance type controllers. For I.C. controllers which use variable voltage sensors, voltages are measured instead of resistances.

Differential Controller Checks

1. Check power supply to controller.

2. Check that all components are wired correctly to controller (according to manufacturer's specifications).

3. If the pump or valve does not work in the "manual" mode, disconnect it from the controller and apply rated voltage to its input wires at the controller.

    a. If it runs, the pump is all right - the problem is in the control system.

    b. No operation - the pump or valve is faulty or the interconnecting wiring or relay is faulty. Isolate the fault and repair or replace the defective component.

4. Check all sensors for:

    - proper location,
    - secure attachment with no corrosion build up,
    - proper wiring to controller.

5. Check each sensor for proper resistance by disconnecting it at the controller. If the measured resistances are as specified, the fault is a controller problem. Proceed to Step 8. If the measured resistances do not correspond to the specification value for the temperature of the sensor location, then:

   - the sensor is faulty,
   - the interconnecting wiring is faulty.

6. Disconnect sensor from wiring leading to the controller. Check the sensors resistance at this point. If the resistance is not to specification, replace the sensor.

7. If sensor is accurate, check for corrosion at all wiring connections. Clean, reconnect and remeasure resistance at the controller. If the measured resistance is still not correct, replace the wiring between the sensor and the controller.

8. Controller operational check.

   - switch off the electrical power to the pump and make sure the controller is set for the recommended temperature differential;

   - replace the temperature sensors at the collector and the tank with variable resistors (variable resistors with readouts will simplify the procedure). The resistors can be connected to the sensor terminals at the controller;

   - from the temperature sensor characteristic curve, determine the resistance associated with $5^{o}C$ absolute temperature;

   - dial this resistance into the variable resistor on the output to the tank sensor. Record the resistance;

- with the controller set in the automatic position, gradually change the resistance on the collector side until an output is measured at the controller output terminals (to pump or control valve). Record the indicated resistance;

- vary the resistance until there is no longer an output at the controller output terminals. Record the indicated resistance;

- reset the tank variable resistor for the resistance associated with a 15°C absolute temperature;

- repeat the above procedure determining the collector resistance to receive an output at the output terminal and the resistance to receive no output. Record both resistances;

- calculate the differential resistance, and from the temperature sensor characteristic curve determine the temperature differential;

- compare this with the original setting of differential temperature;

- if the two figures disagree substantially (more than ten per cent), adjust the controller setting and repeat the above test.

9. Sensor Calibration Check

Preparation

1. Obtain a copy of the temperature sensor characteristic curve from the manufacturer (resistance vs. temperature).

2. Use a digital multimeter with an appropriate probe to determine as accurately as possible the temperature at the point the sensor is intended to sense.

Method

Determine the temperature at the point the sensor is intended to sense. These will likely be the temperature on the absorber plate in one of the collectors and the temperature in the lower third of the storage tank.

Measure with an ohm meter the resistance shown by the sensor. This should be done at two temperatures for each sensor, for example:

For collector sensors:

1. Cool Temperature - as early as possible in the morning, preferably on a cloudy day.
2. Hot Temperature - mid to late afternoon on a sunny day.

For storage tank sensors:

1. Cool Temperature - after a major draw of heat from storage to load on a cloudy day and before the auxiliary heat has replenished the draw (where applicable).
2. Hot Temperature - late on a sunny day before a major draw of heat or on a day when the load is reduced.

Compare the measured resistance with that shown on the manufacturer's table or graph for the appropriate temperature.

If the resistance varies from the expected value, the sensor or sensor lead connections may be corroded or the sensor may have been damaged by heat extremes. Check both and replace as necessary, then repeat the test.

Freeze Protection Controls

Thermal switch sensors are used for freeze protection of the collector loop on drain back systems or heat exchangers on closed loop systems.

The freeze protection set point should be at least 3°C (5°F) above the actual freezing point. Once the thermal switch set point is reached, the switch should de-activate the pump on drain back systems, causing the system to drain. In closed loop glycol systems, the freeze protection thermal switch circuit prevents the pump running due to controller failure.

Sensors used for freeze protection may be either the thermal switch type or variable resistance type.

Test Procedure for Thermal Switch Type

1. Connect the thermal switch to an ohm meter so you can see when it changes state. Seal the sensor along with a thermometer in a plastic bag. Place the bag into cool water and add ice for further cooling. When the sensor changes state, record the temperature and ohm meter reading. Slowly warm the water and sensor until it changes state again. Record the temperature and ohm meter reading. The first set of readings is the low temperature limit set point and the second is the temperature at which heat collection can restart.

2. After checking the thermal switch, connect it to the controller or pump circuit and retest by varying the temperature as described, and verify that the proper response occurs.

Test Procedure for Variable Resistance Types

1. If freeze protection circuit uses a thermistor, nickel wire or film as its sensor, then a variable resistor whose resistance range passes through that of the low temperature set point should be connected to the collector sensor inputs. A resistor with a value somewhat less than the collector freeze point should be connected to the storage input. With the appropriate load connected to the controller, connect the controller to the power input. The variable resistor should be varied above and below the freeze protection set point. Verify that the appropriate response occurs at the temperatures and resistance values specified by the manufacturer.

High Temperature Limit Protection

High temperature limit switches are used in solar systems either to protect collectors and storage tanks or as a secondary safeguard against failure of the mixing valve on the outlet to load.

The collectors are normally designed to withstand the stagnation temperatures and thermal shock associated with this. Control logic should be set up so that the temperature limit switch will not inhibit the initial start up of the collector loop pump, but will activate if, after a reasonable length of time, the collector temperature has not fallen.

For closed loop glycol systems, the high temperature limit or control logic may be used to divert flow to a heat purge coil.

High Temperature Protection for Storage Tanks

High temperature limit switches are used to protect storage tanks from over temperature conditions. In some cases, a tank temperature limit can serve as a secondary protection against scalding temperatures being delivered to the load if the mixing valve fails.

High Temperature Limit Switch Checkout

The checkout procedure is similar to that for freeze protection. The switch or sensor is immersed in hot water, which is heated until the device activates and then cooled until it reverses. The temperatures and resistances for these points are recorded and checked against the specification.

GENERAL SYSTEM DIAGNOSTIC PROCEDURE

The performance of a solar system depends on the interaction of all system components, outside conditions, and the load imposed on the system.

There are cases in which a general decrease in the performance of a system is indicated by a decrease in system operating time, temperature differences, measured energy collected, or by an increase in the required auxiliary energy. In some cases, the particular problem cannot be isolated by the operator. The following is a general diagnostic procedure which can, in most cases, isolate the causes.

Carrying out this procedure requires some knowledge of solar systems and a number of portable instruments; therefore, a troubleshooting technician or engineer may be required.

1. The first step is a visual inspection of the system paying special attention to such items as completeness and condition of insulation and whether the collectors are clean and free of new shading.

2. Verifying flow rates.

   The operating flow rates in each loop should be checked by the means provided. This may be by using pump differential pressures or by reading a flow meter if one is installed in the particular loop. (See commissioning procedure.)

3. If the flow rate in any loop in the system is lower than specified the flow, restriction can be isolated by checking the pressures at the monitoring points provided in the system and comparing these with the commissioned values.

4. If the flow rates in all points of all loops are as specified, check the fluid temperatures at each monitoring point on a clear sunny day.

5. Verify the flow balance through the collector banks.

   The face temperature of each collector should be checked by feel or, preferably, with a pyrometer. Collectors that are significantly warmer or cooler than their neighbours indicate flow blockages and stagnation or high flows respectively.

   It is a good idea to check the bank temperature balance by the method shown in the commissioning procedure.

6. Verify the effectiveness of the heat exchanger as in the commissioning procedure. A reduced effectiveness could indicate scaling of the heat exchanger surfaces.

7. Perform the preliminary thermal performance test as shown in the commissioning procedure and compare the efficiency with the commissioned values. This will detect degradation of the collectors' performance.

8. Check the calibration of the control system as described in "Troubleshooting Solar Controls."

If satisfied that the operating characteristics of the system are normal, investigate the non-operating features.

9. Isolate the system from load and bring the storage temperatures up during the day. Read the storage temperature at nightfall and shut off the system. Check the storage temperature in the morning. If the storage temperature has dropped significantly, suspect damaged or wet insulation, or reverse thermosyphoning (usually the result of a faulty check valve).

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